



Proceedings of the 4th Forest Engineering Conference: *Innovation in Forest Engineering – Adapting to Structural Change*

White River,
South Africa

April 5 - 7, 2011



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Innovation in Forest Engineering – Adapting to Structural Change

**Official Proceedings (Extended Abstracts) of the
4th Forest Engineering Conference
Held at White River, South Africa
April 5 - 7, 2011**

Edited by: Pierre Ackerman, Hannél Ham, & Elizabeth (Lise) Gleasure

Preface

I am indeed honored to provide the introduction to this volume of proceedings on behalf of the Forest Engineering Conference of 2011 technical review and organizing committee. These proceedings represent scientific contributions to the Fourth Forest Engineering Conference, titled ***“Innovation in Forest Engineering – Adapting to Structural Change”*** presented in White River, South Africa, from the 5th to the 7th of April 2011. The Conference was jointly hosted by the Stellenbosch University's Department of Forest and Wood Science and the International Union of Forest Research Organizations (IUFRO).

The Forest Engineering Conference (FEC), an international event held every four years, is a forum for forest engineers from around the world to share their research, knowledge, experience, and emerging ideas with the forestry community. The stewardship of the FEC lies with the international forest engineering community as a whole, and this conference is the culmination of a number of events with South Africa being fourth country to host the FEC. This meeting follows previous successful FEC conferences held in Mont-Tremblant, Canada (2007); Växjö, Sweden (2003); and the inaugural event in Edinburgh, Scotland (1999). The high quality of material presented by the presenters and the large number of delegates attending FEC 2011, attest to current and continued interest in promoting the all-important facet of Forest Engineering in the international forest industry.

I would like to thank all those who were involved in the organization of this symposium for their significant contributions to the success of this event. In particular I would like to thank Jean-Francois Gringas who provided the organizing committee with invaluable information gleaned from the 2007 meeting in Mont-Tremblant, as Stellenbosch University volunteered to undertake the presentation of the meeting at short notice. I would also like to thank Hannel Ham, Lise Gleasure and Poppie Gordon for their hard work and dedication which has most certainly contributed to the success of this conference.

FEC 2011 is indebted to the authors of the extended abstracts included in this volume as well as attending delegates who have travelled from far and wide to share this event with us. I would also like to thank our sponsors; Southern Mapping, Tigercat, Bell, John Deere, Mondi, Forest Engineering South Africa (FESA), Husqvarna, Komatiland Forests, Merensky, SA Forestry Magazine, Stihl, Wood Southern Africa & Timber Times and York Timbers for their generous financial contributions.

These proceedings are reproductions of extended abstracts submitted to the symposium with editing to achieve consistent format. No attempt was made to review or verify results, although the abstracts were reviewed for suitability by members of the symposium scientific review committee as set below. The following experts served as extended abstract reviewers for the Fourth Forest Engineering Conference 2011 in South Africa:

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March 2011

Pierre Ackerman

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Opening Address

Innovation and adaptation: Overcoming challenges and optimizing the forest industry

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Since the establishment of plantation forestry in South Africa in the 1870's, the industry has faced a number of challenges, undergone numerous changes and advanced into the international area. A number of the changes made and advances gained were driven by many aspects including the demand for more timber, the demand for higher quality timber and, of course, a demand for less expensive timber through higher production and reduced generation of waste. These challenges have been over time addressed by research and development in areas including tree breeding, silviculture, forest protection and forest engineering.

If we look back in time, a number of the challenges we face in today's forest industry have in some form followed a trend. These include harvesting techniques and equipment, timber transport and timber conversion and the complete value chain. If we look at the 1931/1932 financial year, the Department of Forestry total expenditure was approximately £537,638 compared to the £34,859 received from the sale of 44,400m³ of timber. During this period the biggest problems were insufficient extraction methods and poor transport infrastructure. Road systems were poor to non-existent and, for the first time, the use of aerial ropeways was suggested. In the 20 years to follow, the transport infrastructure made significant advances with 125 trucks being utilized for timber extraction and transport, yet still more than 2100 animals including oxen, horses, mules and donkeys were still utilized. It was also at this time that advances in forest engineering became evident with the implication of the first high lead and skyline systems. By mid-1960's specific awareness was first focused on improved labor productivity through mechanization and improved production methods. The first wheel skidders were soon introduced followed by tree-length skidding and transport. However, the fuel crisis in the 1970 slowed down mechanization within forestry as the industry became energy conscious. Although this period might have slowed mechanization in the sector, it also has contributed to some of the strides made in forest engineering development.

If one looks at the main focus areas in this brief overview or highlights of the 100 years from the 1870's to the 1970's, some areas that stand out are *harvesting*, *extraction*, *transport*, *productivity* (both operations and labor) and *energy consumption* or *energy conscious management*. Is it not these areas that are currently receiving attention in the industry? Looking at the research focus themes of Forestry Engineering South Africa for 2009, one reads *harvesting*, *roads*, *transport*, *people* and *bio-energy* to mention a few. These themes are by no means the only themes receiving attention, but it is interesting to note the trends or focus areas have not changed drastically over the last 140 years.

Even though the themes seem to present some form of continuity, there has been without any doubt been overwhelming changes and advancements with regard to forest engineering. We now transport larger quantities of timber over longer distances at a lower cost than ever before. We utilize more of the resource on site and have reduced waste in the processing plants. Productivity has increased due to the implementation of newly developed technologies and assisted decision making throughout the value chain by implementing optimization models and systems. These changes throughout the history of forestry emphasize the innovation that has contributed to the growth and improvement of the industry. Due to research and development in forest engineering,

the industry has been able to innovate and adapt to changes and challenges forced onto the industry due to changes in the international political and financial landscape. In order for South Africa to remain internationally competitive and ensure the forest community can ensure a sustainable supply to feed the growing global timber demand, the current efforts of role players in forest engineering research and development should be maintained. It is however important to remain vigilant of continuous changes and shifts within the sector that influences and eventually steers research and development in forest engineering.

KEYNOTE 1

Forest Engineering in South Africa: Delivering, at the lowest cost, sustainably

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Deliver, at the lowest cost, sustainably. This is the function of the forest engineer.

Job one is to deliver whatever it takes. Job two is to minimize delivered wood costs and job three is to do so sustainably. Any fool can do jobs one and two; doing them sustainably (socially, environmentally and economically) is the real challenge.

If forest engineers share a common function, then in all likelihood they share common challenges. Rising costs, falling productivity, a scarcity of skills, an abundance of environmental legislation, collapsing infrastructure, expanding regulations, more demanding customers, less viable suppliers, stricter safety standards and growing worker and community expectations are some of our local challenges. Clearly they are not unique to South Africa and they frustrate the forest engineer in fulfilling their function.

How have we dealt with these challenges, what have we been taught and what can we teach? How are we adapting to ensure that we continue to deliver, at the lowest cost, sustainably? This presentation reviews South Africa's response to, amongst others, the following issues: safety, certification, outsourcing, roads, mechanization, transport and worker and community expectations.

The South African forestry industry has much to teach. It has a world-class safety performance, is almost entirely FSC certified and is at the forefront of transport technology. It also has much to learn including how to ensure the viability of contractors, implement large scale mechanization and meet the needs of workers and communities.

South African forest engineers have realized that to remain globally competitive they have had to become wise teachers, quick learners and above all fast adaptors.

KEYNOTE 2

An industry in transition: How technology is re-inventing the Canadian forest sector

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The global recession and the major decrease in both demand and prices of traditional forest products especially in the U.S A. have had a dramatic impact on the Canadian forest industry. A large number of pulp and paper and wood product mills have curtailed production or shut down completely in the last decade, resulting in thousands of job losses. We are facing many challenges related to the resource itself, our industrial infrastructures and our traditional markets. It has become clear that the commodity market for forest product can no longer be the sole business strategy in many regions of Canada because of the high fiber costs and the lack of competitiveness of some mills when compared to other regions of the world. This paper outlines the structural changes that this situation is causing in the Canadian forest sector and how a new R&D agenda is helping to drive these changes towards a sustainable bioeconomy through innovative technologies and engineering solutions.

A major part of this structural change is the need to shift production focus from low-value commodities to higher-value bioproducts and value-added manufacturing. The keystone to success is innovation. Historically, the Canadian forest sector has been very good at process improvement to reduce costs but weak in product and business-process innovations. In response, FPIInnovations, a public-private partnership, was created in 2007 by merging four independent research organizations, Feric, Forintek, Paprican and the Canadian Wood Fiber Center, with an objective to embrace innovation from a value chain market-driven perspective.

The complete R&D agenda of FPIInnovations and its partners is aligned with the strategic directions outlined in a Memorandum of Understanding that was signed in 2008 between FPIInnovations and the government of Canada (Smith and Hector 2010). In addition, four new university-based research networks were given funding by the National Sciences and Engineering Council to promote basic R&D work in areas aligned with the defined priorities of the forestry sector and FPIInnovations.

In addition to a structured innovation process and philosophy, FPIInnovations was provided with special funding by the federal government to develop transformative technologies aimed at re-inventing the forest sector in Canada. These new technologies and engineering improvements will take advantage of the unique attributes of Canadian wood fibers to develop promising new biopathways for the future. For example, on the solid-wood product side, efforts are directed at producing innovative building systems that incorporate knowledge and engineering into ready-to-use construction solutions for single or multi-level wood structures. In pulp and paper, the direction is toward the production of innovative products such as bioreactive papers and exciting new materials such as nanocrystalline cellulose (NCC). NCC presents many opportunities for applications outside of the forest sector such as chemicals, plastics and paints. As in many other forested countries, forest biomass for bioenergy and the production of biofuels appears to be a logical extension of the traditional product portfolios and a more optimal use of the forest resource.

In the long term, biorefineries producing an array of bioproducts in addition to traditional products will become common.

In forest operations, new process control tools such as FPIInnovations' FPSuite package of hardware and software enable forest managers to monitor and control their operations in real time. The FPDat for example is a powerful on-board datalogger that captures production and spatial data seamlessly feeding a centralized production and wood flow monitoring database. This information can thereafter be used to optimize inventory levels, trucking and delivery schedules. New enhanced forest inventory tools based on LiDAR data, high-resolution digital imagery and individual tree crown analysis are providing much better information regarding forest, stands and tree attributes than ever before. The combined use of these types of tools will enable the forest sector to implement value-chain optimization strategies to deliver the right logs to the right mills at the right time.

Despite the many challenges faced by the sector, not the least being the lack of receptor capacity for innovation and technology created by the severe staff reduction in recent years, there is a shared belief that the future is positive for the Canadian forest industry. We are blessed with abundant, sustainable and high-quality forests; we just need to develop strategies to maximize the value generated from this asset. FPIInnovations is in itself an innovation; a public-private partnership between governments and private industry, responding to global challenges in the marketplace through the development of a new innovation process focused on clients and markets for new products and technologies through a value chain optimization perspective.

KEYNOTE 3

Harvesting system and production improvements in New Zealand's steep terrain

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Plantation forest industry in New Zealand experienced significant growth in the early 1990's driven by very good export log prices, with some additional 400,000 hectares planted over a 6 year period. With our typical rotation age of 25-28 years, harvest volume is expected to increase 30-50% over the next 10 years. Much of these new plantings were on steep and erodible terrain, as well as in more remote locations and often in smaller blocks. Given the current suppressed international market and NZ reliance on export of its wood products, a significant increase in road and harvesting costs could make these forests marginal or even uneconomic to harvest and manage.

Both the industry and government have recognized the seriousness of the issues and are investing a combined NZ\$6 million into steep terrain harvesting research over the next 6 years. This research is being coordinated through a new collaborative entity called Future Forest Research (FFR). The industry has set up a harvest benchmarking system that tracks productivity and costs for commercial scale forest operations. It allows tracking of changes over time, but also the ability to differentiate based on system, stand and terrain parameters. The mainly manual steep terrain harvesting cost exceeds that of the more cost-effective mechanized ground-based systems by NZ\$10/m³.

While mechanization of log processing on the landings is advanced for steep terrain operations, new machines and systems are being developed to mechanize the felling and allow for pre-bunching on the steep slopes. Successful trials have been conducted using an excavator tethered to a bulldozer, as well as one with an advanced built in winch to aid traction.

Efficient use of cable yarder systems will also be critical to optimize productivity. Mechanized felling can aid subsequent extraction, and higher productivity rigging configurations, such as a grapple, can be considered. A survey of current yarders operations shows that very few crews use carriages or grapples, and a guideline on the advantages of various rigging configurations is being developed. Tests have also been carried out on a new generation of radio-controlled chokers. They are lighter and more reliable than previous versions. The benefit of time and motion studies was highlighted in their evaluation in that time won in the unhooking phase was being lost through reduced turn volume associated with the additional difficulty of hooking up the radio-controlled chokers.

Swing yarders and their ability to operate on smaller landings, often coupled with two-staging operations to concentrate log making operations, are becoming more common in New Zealand and when used in the correct situation increase cost-effectiveness.

To access the new harvest areas considerable investment is also being made in expanding the forest road network. Construction standards associated with public roads are often not applicable to forestry. Specific issues for many of the new forests include poor sub-grade strength and the high cost of bringing quality aggregate to the site, but also simply the lack of a fit-for-purpose

design procedure. Through testing of subgrades and aggregates at the School of Forestry a more comprehensive understanding of road performance is being developed.

Overall the NZ forest industry is in a positive mood, with good sales, new investments and employment opportunities. The government is also making all the right noise about supporting the forest industry at large to become not only a cornerstone of its carbon reduction policy, but also an important player in earning export revenue. The immediate future is bright, but would be brighter still if we can really improve the cost-effectiveness of our harvesting our steep terrain forests.

KEYNOTE 4

Development of more efficient forest fuel supply chains

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Abstract

Renewable energy is an important part of the Swedish energy budget. With a renewable share of 47 per cent, closing in at the EU RES directive national goal of 49 percent, Sweden has a unique position among the industrialized countries. Forests play an important role, but much of its potential remains untapped. Wood is the foremost traditional energy source in Sweden, but current, industrial-scale utilization has developed in the period after the 'oil crises' of the 1970's. At that time, practically no forest biomass was harvested for energy. Today, one third of the energy budget is based on forest biomass, most in the form of industrial residues from Sweden's comprehensive forest industry. A growing share however is consisting of primary forest fuels, i. e. material harvested for energy purposes.

Primary forest fuels consist of diverse fractions such as logging residues (branches and tops), stumps, small trees and other wood not in demand by the conventional industry. Thus, the supply depends on the intensity of conventional logging. Half the gross supply is exempt for ecological or techno-economic reasons. The remaining annual net supply is around 17 million cubic meters solid of stumps and logging residues from final felling and over 5 million cubic meters solid of small trees from young stands. Today, around 7 million cubic meters are harvested, mainly in the form of logging residues and sub-standard roundwood. Although the full primary fuel potential of Swedish forests cannot be economically harvested, it is possible to more than double the annual utilization.

The nature of forest energy operations is challenging. The available primary forest fuel feedstock combines difficult operational properties such as bulkiness, small piece size and scattered occurrence with low relative value. The operations also must be performed under the constraints of a sensitive environment with no or low negative impact on soil, water and any growing forest stand.

In Sweden, the development of forest fuel operations started in a simple way. Resources from main logging operations were becoming available as a result of continuous rationalization. The surplus of forwarders could be employed in residue extraction with very limited modification, and chippers mounted on forwarder chassis provided in-terrain platforms capable of both extraction and production of an acceptable fuel. Apart from the existence of available machinery and skilled labor, four other drivers play an important role in the strength of Swedish development.

Firstly, the emergence of a functioning market and bio-energy infrastructure has been a key element. Two segments are worth mentioning in particular. The district heating systems started using wood fuels in a small scale around 1980. In 2010 they used equivalent to 17 million solid cubic meters of wood fuels every year. The other important player, using a similar volume, is the forest industry itself which has developed from being heavily dependent of fossil fuels into being a self-sustained net seller of green energy.

Secondly, the political will to escape from dependence of imported fuels and, instead, secure a domestic supply of energy has been persistent and mostly sound. The Swedish government has not imperatively demanded from market players to take any particular action, but through taxation, tariff and certificate systems made it 'good business' to gradually develop efficient renewable

alternatives. But the competition from fossil and other energy sources is always present, providing incentive for continuous improvement.

A third driver for increased use of forest biomass in energy conversion is the recent focus on fossil carbon dioxide and following concern for risks of global climate change. The Swedish standpoint is that sustainable, well managed forests play an important role in a switch-over to renewable energy systems with low impact on climate and environment.

In practice, economy remains the basic driver. In 2007, a four-year national R&D program, *Efficient Forest Fuel Supply Systems*, was launched by the Swedish forest and energy sectors, and is strongly supported by the Swedish Energy Agency. The principal aim is to increase the use of forest biomass for energy and the means are increased efficiency, lower costs and higher quality of the produced fuels. Results include new technology, new supply chain design and in-depth knowledge of the operational milieu of forest fuel operations. The main elements of cost reduction identified are

- Purpose-built technology for key forest fuel operations
- Deepened integration of fuel operations with main logging
- Operator training improving performance and quality of work
- Improved information chains for better control, planning and management of production
- Increased co-operation between the supply chain tiers
- Re-engineering of supply chains for concentration of heavy operations such as chipping
- Improved intermodal transport systems making distant fuel sources accessible

The program has demonstrated measures that would lead to substantially lower costs. Alternatively, it is possible to double the production of primary forest fuels, within current cost levels. Recently, the funders decided to continue development through financing a new four-year period, 2011-2014, with the scope of further developing the efficiency and purposefulness of forest fuel operations.

Session 1

New Equipment Monitoring Approaches
Chaired by: Tomas Nordfjell & Mark Brown

Onboard computing selection and implementation guides

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Experience in Europe and North America has shown that effective use of onboard computing equipment in forest harvesting machines can produce gains of up to 30% in availability, utilization and productivity. The key barriers to the uptake of onboard computing in Australia are the lack of information both about its capabilities and about what type of computer to use to address particular concerns (eg. poor utilization, machine comparisons, fuel efficiency). The only area where there has been widespread uptake is bucking optimization for radiata pine harvesting. This has been driven by the requirements of forest managers.

Results of trials installing and testing onboard computing equipment in Australia have been used to develop an online Selection Guide. Users of the guide select their problem or concern from a list and are taken to a description plus examples, key points and case studies of the onboard computer(s) best suited to address that concern. Four categories of onboard computer (vibration sensor, GPS, purpose-built and manufacturer) were identified. Basic steps needed to implement each category of onboard computer including installation; setup and basic information on the use and analysis of the data collected by the computer are also covered in the guide.

Materials and Methods

An initial study identified a number of onboard computing systems with the potential to improve harvesting machine performance. Three trials were established to test the most promising of these onboard computing systems across a range of Australian forest harvesting systems and forest types (natural forest, radiata pine plantation and blue gum plantation). An additional trial was established when the opportunity arose to test a pre-release version of FPIInnovation's FPDat¹.

The natural forest harvesting system trial was located in the Central Highlands of Victoria. The system consisted of a harvester with a felling grapple head, grapple skidder and two excavators with log grabs and cutoff saws. Tree lengths were skidded to a central landing for processing and haulage. A Multidat² (FPIInnovations, formerly FERIC) and Garmin 276C GPS (for display purposes) were installed in the harvester and skidder. One excavator had a Multidat only installed. Each Multidat had an internal GPS unit. The skidder had a high-precision GPS unit (SX1) whereas the other two machines had low precision GPS units (Garmin 15).

The radiata pine harvesting system trial was located in the south-east of South Australia. The system consisted of a single grip harvester, two forwarders and an excavator used by truck drivers to load their trucks. Trees were bucked at the stump and logs forwarded to the roadside for haulage. The harvester had an existing Dasa 4 onboard computing system that was upgraded with a GPS. A Dasa forwarder computer³ with the optional GeoInfo GIS/GPS was installed in one of the forwarders.

The blue gum plantation harvesting system trial was located in the south-west of Western Australia. The system consisted of three feller-bunchers, three grapple skidders and three infield flail delimber/debarker/chippers with whole trees being chipped directly into trucks. RouteHawk⁴ systems were installed in a harvester, forwarder and chipper. Due to the difficulties in getting the

¹ <http://fpsuite.ca>

² <http://feric.ca/en/index.cfm?objectId=3ADAB84A-C09F-3A58-EA3EA190F58D4E5E>

³ <http://www.dasa.se/website1/1.0.1.0/58/2/>

⁴ <http://www.strongeng.com/tracking.html>

RouteHawks functioning, a supplementary trial was established using Multidats in each of the three flail delimber/debarker/chippers.

An additional trial was established in a radiata pine plantation in Eastern Victoria. The system consisted of two single grip harvesters and two forwarders transporting logs cut to length at the stump to the roadside for truck transport. An FPDat was installed in one of the forwarders to track the type, quantity and location of logs at roadside as an input into a truck dispatch system.

Machine performance data (machine utilization and productivity, delay length and cause, and GPS positional data) collected from the onboard computers in each of the trials was used to identify areas for improvement in each harvest system and to provide case studies and practical information about installing, implementing and trouble-shooting the onboard computers for the Selection Guide.

Results and Discussion

Information gathered from over 12 months of implementation and testing of onboard computer equipment over the four trial sites was used to develop the online Selection Guide. The Guide informs users of the most appropriate onboard computer(s) for their purposes and its potential pros and cons.

The first step for users of the Guide is to select the issue or problem they would like to tackle from a list (eg. poor utilization, machine comparisons, fuel efficiency). Each issue or problem is linked to one or more of the following broad categories of onboard computer:

- Vibration sensor
- GPS
- Purpose-built
- Manufacturer

Each category has a brief description of the capabilities of the onboard computers, key points to note, and examples with indicative costing, case studies with estimated costs and returns and installation implementation with trouble-shooting advice.

Key findings from the onboard computer trials included:

- Need for buy-in from the company and machine operators. This is particularly important when operators are required to enter data. Related issues include the need to consider procedures to transfer data to and from onboard computers and to analyze data and act on findings.
- Recognition that improvements in one aspect of a system can expose bottlenecks elsewhere in the supply chain. For example, in the natural forest trial, improvements in harvesting efficiency initially exceeded the haulage capacity.
- Good support from the equipment manufacturer is essential for successful implementation of onboard computing equipment, particularly the more sophisticated purpose-built and manufacturer units.
- Considerable interest was expressed by machine owners and forest managers in the potential for onboard computers to improve their forest harvesting operations.

Acknowledgements

Support for this project has been provided by Forest and Wood Products Australia, VicForests, M and R Harvesting, ForestrySA, Kettle Logging, L.V. Dohnts and Hancock Victorian Plantations.

Standardized operational monitoring data – development and implementation

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General background

Forest machines are becoming an increasingly important data source in forest information systems. This means that the need for exchanging information with forest machines is increasing and therefore there is a continuous need for development of standardized communication.

StanForD (Standard for Forest machine Data and communication) was introduced in 1987-89, parallel to the introduction of optimizing computers in harvesters. The standard is an open de-facto standard used by all major CTL manufacturers.

Present StanForD

The present standard is flexible, backward compatible and small in size. The basic building blocks of the standard are definitions of approximately 900 variables, 20 different file types, and a communication protocol based on Kermit. All data are stored and transferred in ASCII format. The most commonly used file types are:

- bucking instruction (apt-file).
- harvester production data (prd-file).
- detailed harvested stem data (stm-file) .

New StanForD2010

Due to the properties of the old standard, we have a situation with many old structures of little use and a large number of complex aggregated data. The StanForD members decided in 2008 to upgrade the standard to meet the demands of modern computer communication as well as using the possibility to remove un-utilized parts of the old standard. The new version is built on XML format and will be introduced in 2011.

The main objectives of the new standard version are to achieve:

- Improved structures that support modern data management
- Better structural descriptions
- Stricter implementation rules
- Reduction of complex aggregated structures

The following messages will be included:

- Object, Production and Species group instructions
- Geographical instruction
- Forwarding instructions
- Harvested and Total harvested production
- Harvesting quality control
- Forwarder production and Quality control
- Geographic report
- Operational monitoring

Organization

The standard is coordinated by Skogforsk and Metsäteho with participation from all major manufacturers in northern Europe as well as Swedish and Finnish forest companies. Two official

open meetings are arranged annually and all documents can be found at www.skogforsk.se. The manufacturers who financially contribute are Komatsu Forest, John Deere, Ponsse, Rottne, Dasa, Motomit, LogMax and SDC.

Present operational monitoring

A file type for operational monitoring (drf-file) has existed since the 1980's. However, it originally lacked definitions of time concepts and key figures. The standard was therefore updated with an improved operational monitoring around 2005 (figure 1).

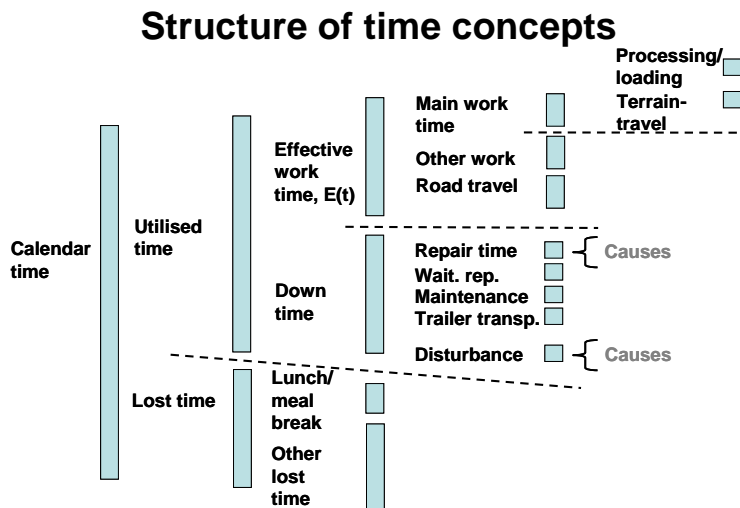


Figure 1. Main time concepts in StanForD.

The objective of the updated drf-file is to make it possible to compare different machine systems, causes for repair, organizations, harvesting sites, and the variation over time (figure 2).

One of the basic ideas when updating the standard was to make it possible to use automatically collected information from the machine, thus minimizing the amount of work-time that the operator needs to spend on this system.

Times

Driver: 1. Tommy

Calendar time: 99:08:17

Basic time: 10:07:17

Basic time (G0): 07:44:42

Total repair time: 00:00:00

Down time: 00:42:39

Time utilized: 10:49:56

Lost time: 88:18:21

Overview | Time utilized | Lost time | Down time | Short down time | Other

Calculating key:

Utilisation:	10.93 %
Technical utilization:	93.44 %
Effectice work utilisation	10.21 %
Interrupt level:	6.56 %
Repair time	0.00 %
Machine availability:	93.44 %

Start and end times:

Type	Date
End time	06-11-24 12:46:18
Start time	06-11-24 12:50:21
End time	06-11-27 14:04:02
Start time	06-11-27 18:36:02
End time	06-11-28 07:08:35
Start time	06-11-28 15:54:35

Figure 2. Drf-file analyzed using Silvia.

Monitoring database

The IT-company Logica together with Swedish forest companies and SMF (Swedish association of forestry contractors) has developed a database for storing and analyzing drf data. The database makes it possible to compare different machines (table 1) as well as allowing detailed analyses of a single machine, for example over time, per operator and logging type.

Table 1. Example illustrating a report for comparing several harvester and operators.

Harvester	Operator	Final felling				Thinning			
		Processing, h	Terrain travel, h	m3/stem	m3/h	Processing, h	Terrain travel, h	m3/stem	m3/h
XXXX	John	71 h	12 h	0,25	15	11 h	2 h	0,11	5
XXXX	Daniel	101 h	18 h	0,23	14	0 h	0 h	0	0
YYYY	Jakob	86 h	13 h	0,27	16	0 h	0 h	0	0
YYYY	Oscar	99 h	17 h	0,21	13	0 h	0 h	0	0

Future operational monitoring

A weakness with the present standard is that only aggregated data is normally registered. Only the total processing time per operator is normally registered in the drf. This means that it is only possible to extract the total monthly effective work time per operator if the drf-file covers a specific month and not the daily work carried out by a specific operator.

In the new monitoring message (mom) of StanForD2010 each individual time is to be registered. This means that we can create complete time lines/axes that can be used to analyze exactly what was done in the machine at any specific time. It will also be possible to register reasons for different down-times as well as production, fuel consumption and covered distance (figure 3). The basic definitions of time concepts and key figures will not change.

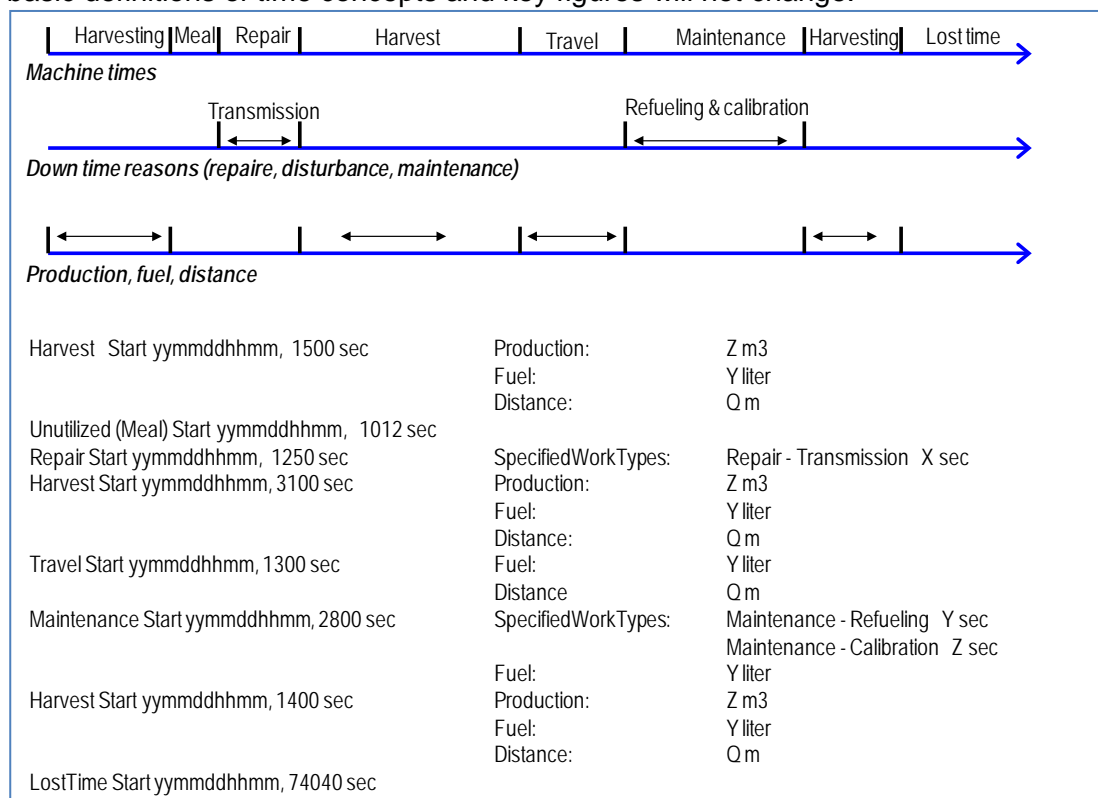


Figure 3. Machine time registration as time lines and table.

The new mom-file will also include operator specific data, both inside and outside the machine (figure 4). This means that the mom-file can be used also as a basis for paying the operator.

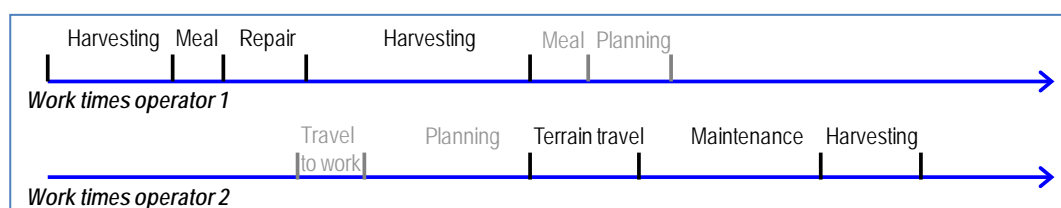


Figure 4. Operator work time registration.

Observe that the identity of the harvesting object (site) is always to be registered for each individual time and that many site parameters can be included. This new structure will thus give us a significantly improved flexibility when analyzing mom data. It will be easy to calculate key figures that are broken down based on a large number of parameters.

Using robust regression for creating productivity functions based on large follow-up data sets

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As presented at the Fourth Forest Engineering Conference.

GPS coordinates in three dimensions – giving the most economical forwarding route

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Forwarding accounts for about 10% of the total raw material cost of the forest industry in Sweden. Hence, minimizing the terrain transportation is important in order to reduce the land damages, reduce the fuel consumption and render overall forwarding more effective. In order to find effective forwarding routes, given the harvester tracks from GPS coordinate information, an accurate identification and description of the road network is essential. The harvester road network will be passed on to the forwarder to plan the forwarding routes.

The harvester creates a road network during harvesting through the harvester tracks. The data of the given harvester roads are produced in the harvester GIS system as a SHP file, together with volume data in the PRI-file, which identify the coordinates of the actual volumes. Regardless of the machine system, the reliability and number of exact coordinates affect the precision of the tracking of the harvester road network.

Most Swedish harvesters have a GPS mounted on the roof collecting coordinate information to the PRI-file and to the harvester SHP file. The accuracy of a normal harvester GPS is about +/- 5 meters. The newest harvester machines on the market in Sweden have a possibility to also use a third coordinate, the Z coordinate. However, since there still is a lack of demand for two dimensional GPS coordinate information in the PRI file, it follows that the demand for a third coordinate (the Z coordinate) is currently marginal. Therefore, these Z coordinates are very seldom registered even if the technology is present. In this study, a Carrier-Phase Enhancement GPS, CPGPS, will be used for manual measurements.

The CPGPS, using angular corrections and having an accuracy of centimeters, gives coordinates in the same way as the standard GPS but also in the third direction. The Z direction gives an opportunity to more precisely decide the road distance, including the gradient of the terrain. A two dimensional and three dimensional road network given from the harvester will thus be compared to see how much the distance differ between the networks.

Having access to the inclination of the terrain of the harvester roads can make it easier for the forwarder driver to find more optimal routing. This can be done either through a 3D visualization in the forwarder GIS interface or possibly in the extension through optimizing the routes, using also the third coordinate.

The field study will be performed during the fourth quarter of 2010, gathering data to analyze and compare the difference of networks based on the two and three coordinate directions.

This study is a part of a project aiming to find optimal routes for forwarding using coordinates in three dimensions along with optimization models. Earlier studies have been carried out for route optimization for forwarders based on the information of x and y coordinates of the harvester's SHP file and coordinates and volumes in the PRI files. As such, knowledge of how the three dimensions will compare to the two dimensional assessment of the road network is an essential contribution to the further development of this model.

Keywords: GPS, coordinates, road network, forwarding

Experiences on on-board monitoring solutions in forest machine maintenance and operator training

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Automatic machine monitoring using advanced on-board data logging and data analysis offers significant new opportunities for forest machine maintenance and operator training. John Deere Forestry launched TimberLink monitoring application for wheeled Cut-To-Length (CTL) harvesters in 2005 and for CTL forwarders in 2009. TimberLink enables accurate, low-cost, long period condition and performance monitoring of large machine fleets. Past experience in using large scale machine monitoring, new fact-based maintenance and operator training opportunities have been very positive. In addition, TimberLink is now within wide use within the forestry research community. Forestry research institutes and universities, especially in Finland and Sweden, have used TimberLink successfully in several research projects.

TimberLink measures machine's performance and fuel consumption continuously during normal operation. The software takes the required information via a CAN bus from the machine's control system. In harvesters several hundreds of low level measurements are taken per each stem. For example, sawing times, fuel consumption during sawing, feeding speed, fuel consumption during feeding and boom usage times are measured for each log. In a similar way, hundreds of low level measurements are taken during forwarder operation. For example, driving speeds, driving distances, fuel consumption during driving, boom cycle time in loading and unloading are measured.

The low level raw data can be further processed producing more valuable machine maintenance and operator training information. For example, saw efficiency can be shown as a function of cutting diameter (Figure 1). This is important information for a service technician assessing technical condition of a harvester. Similarly, as an example, stem processing times can be shown as a function of stem size (Figure 2). This graph includes information, which has proven very valuable for instructors in operator training.

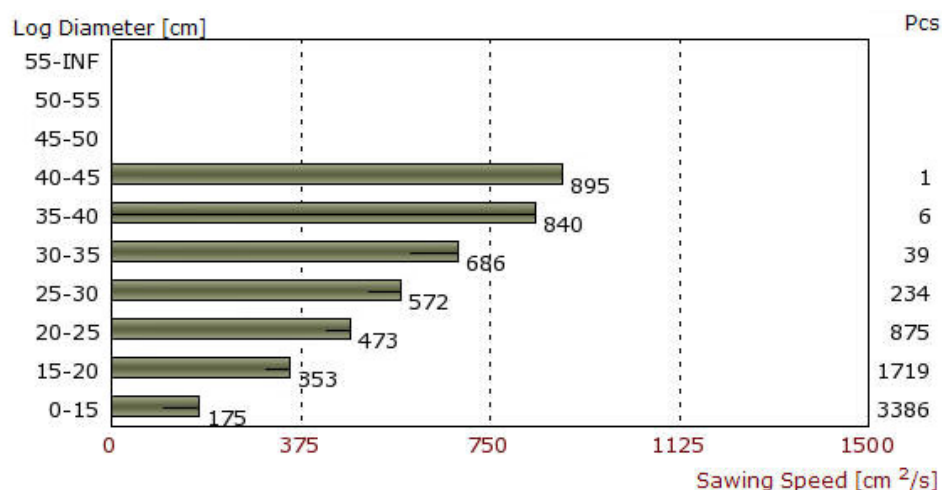


Figure 1. Saw efficiency as a function of cutting diameter

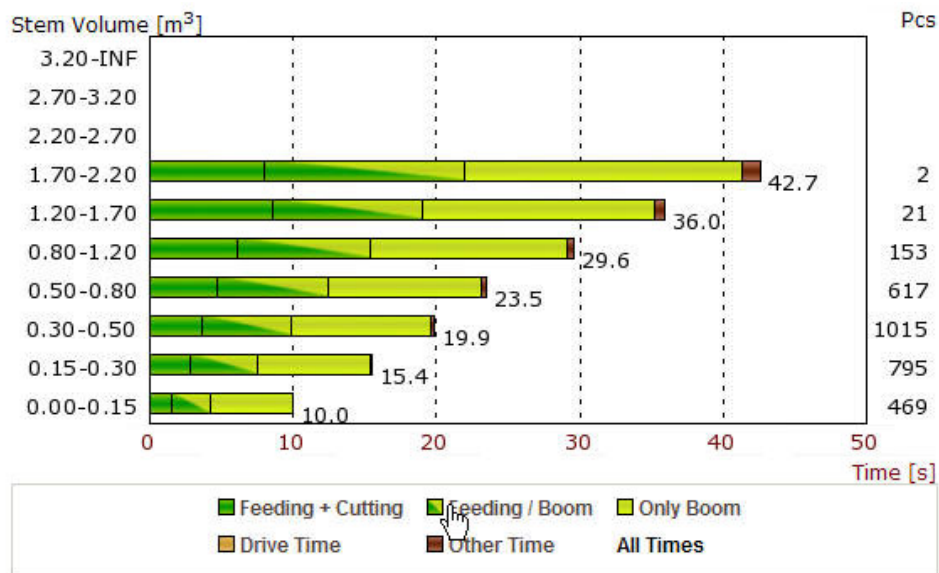


Figure 2. Stem processing times as a function of stem size

Overall machine performance of CTL harvesters and forwarders depends in a complex way on machine model, market area, forest circumstances, species distribution, operator skills, machine settings and other factors. Therefore, interpreting measurement facts, like those in Figure 1 and Figure 2, to select optimal maintenance and training actions still requires expertise. This would suggest that modern fact based practices will more and more replace traditional methods in coming years. The early experiences by John Deere Forestry indicate that the new methods have significant potential to improve both productivity and fuel economy in tree harvesting operations. Improvements come partly from better technical condition of machines, use of more optimal machine settings and, in part, from improved operator skills.

Optimization of the trucking operations from “landing to mill”; an update on available solutions

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As presented at the Fourth Forest Engineering Conference.

Harvester data as a base for management of forest operations and feedback to forest owners

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Background

Modern CTL harvester computers collect standardized production data and other supplementary information at harvesting. Data is automatically collected from the measurement system in the felling head, GPS receiver, harvesting directives and records of operator's decisions. This is a base for efficient management and control of forest operations through immediate feedback to forest owners and updates of forest plans.

When the harvesting operation is completed, the forest owner can get a preliminary receipt on the cut volume and the value, cut area, average stem size, diameter distribution, damage frequency and a prognosis of forest fuel products (branches, tops, stumpages). After a thinning operation, the cut basal area per hectare and strip road percentage can be estimated. If the system has information on tree ages, site index may be estimated for different parts of the object.

Computers in harvesters were introduced in Scandinavia in the middle of 1980s. The first standard (StanForD) for communication with harvesters was released in 1988. The use of data in harvester can be described by three phases:

1. 1990's: Data used only to control the bucking optimization (dimensions and pricelists).
2. 2000's: Production data started to be used as a base for planning and logistics.
3. 2010's: Data is now starting to be used as a base for planning and control of the following processes in the supply chains: the prognosis of forest fuel, regeneration planning after final felling, transparent information to forest owners and updates of forest plans. Wide use of standardized individual stem and log information (pri-files-> hpr-messages by StanForD 2010)

Objectives

The objective of this paper is to present test results from utilization of harvester data for improved planning and accounting. The first practical tests have been made on predicted volumes of forest fuels based on harvester data. The specific goals for these tests were:

- To compare predicted volumes of forest fuels (tops, branches and stumps) with measured volumes at heating plants (based on stand level and sample plots).
- To test a digital map application and harvester data to present area and volume for cut forest and calculated forest fuel volume
- To test harvester data for estimating site indices by using tree height measured by the harvester.

Materials & methods

In the studies, individual stem and log measurements and additional automatic or operator controlled decisions applied on cut trees are stored in the harvester PRI files (Arlinger 2003). For each tree, DBH, species, biofuel stacking and coordinates of the harvester at felling are recorded. For each produced log, origin tree number, log number, assortment, diameter, length and volume are stored. From that information it is possible to re-create the stems (Figure 1). By using the coordinates it is also possible to re-create the whole stand.

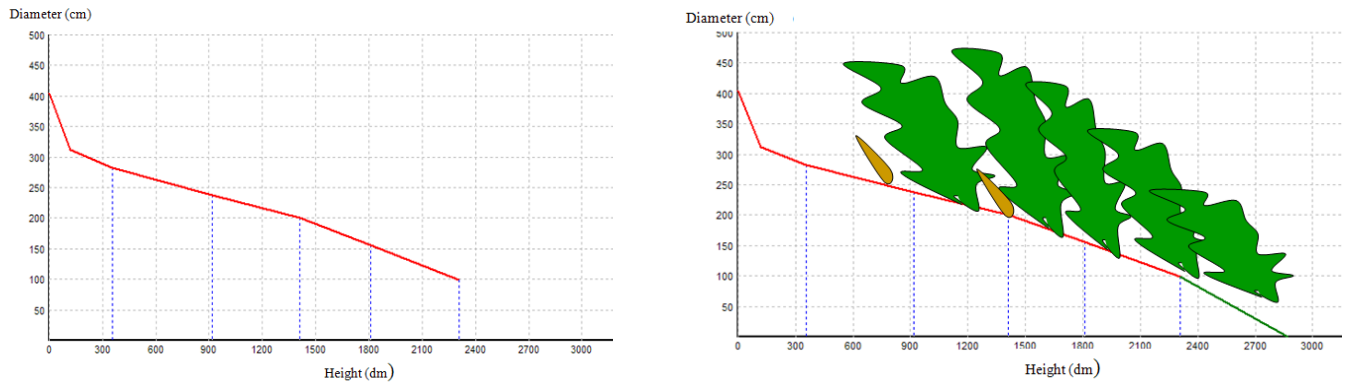


Figure 1. Stem created from harvester data. Step 1 stem a) based of log data measured by the harvester and stored in PRI files. Stem b) top created by function and branch and top quantity calculated by bio mass functions (Marklund 1998).

In the study, harvester data was used to recreate the trees, figure 1a illustrates the cut logs up to the last cut at the top of the stem (Möller 2009). The top is created by using a function (Kiljunen 2002) and the branch and needles is recreated by using different bio mass functions (Hannrup 2009). The study was based on data from the north to the south of Sweden, including 36 sample plots, a total 2000 m² each. All harvested trees in the stands were measured by the harvester and the dry weight of all tops & branches were calculated by using harvester data and bio mass functions. Harvested tops and branches were transported to a heating plant where the dry weights were measured.

In a second step, the site indices (H100) were determined by using the tree height from the harvesters. These site indices were compared with the (H100) site indices manually determined by height/age curves according to Hägglund (1974). In the harvester production file all trees were sorted in ascending order by tree height. From this operation the dominant height was determined as the tree height of the 90 percentile. The site indices were analyzed for each of 16 sample plots. In the study no adaptation of harvester data was made, even though tree ages were deviating from 100 years (at breast height (bh)). In all studied stands recorded tree ages were between 80-120 year (bh).

Results

Estimation of dry weight of tops- and branch quantities

In the studies, 5 different sets of functions were tested (Marklund 1 & 2, Repola and Kiljunen 1 & 2), Hannrup (2009). The standard deviation between function and control was about 10 % for each region when using Marklund or Repola which resulted in the smallest standard deviations. The results showed that small trees gave a systematic overestimation of the dry weight of tops and branches while large trees may result in unbiased or underestimated weights. In total, the result from south Sweden with larger trees gave no systematical error while north Sweden with smaller trees gave an over estimation of the quantities.

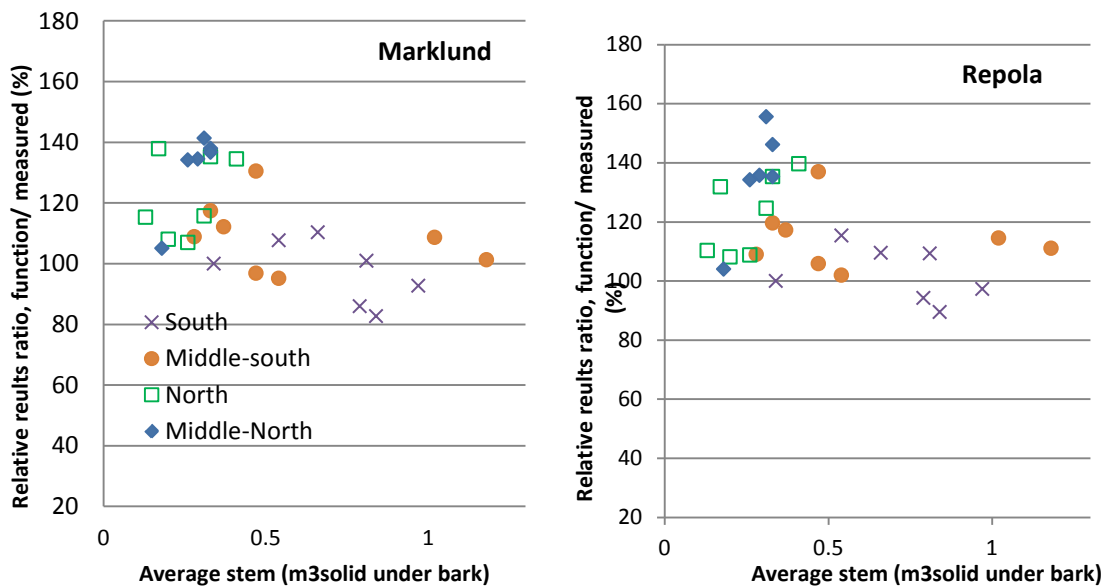


Figure 2. Relative result from Marklund (1988) and Repola (2009) functions plotted against average stem size for 29 Norway spruce dominated plots. The relatively result is calculated as the ratio between calculated dry weight based on harvester data and measured dry weight measured at the industry.

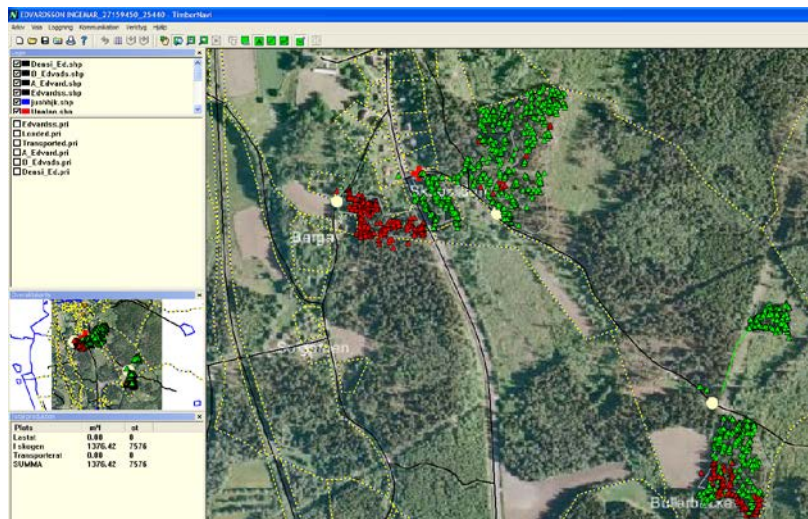


Figure 3. Cut from John Deere's map program, Timber Navi, used in the study. Adapted trees for fuel marked green and not adapted marked with a red symbol.

Comparison between the Site Index decided by harvester and manually methods

The evaluation of a calculation system for automatic estimation of site index (H100) shows a high correlation between harvester data and manual method (figure 4). The standard deviation was 1.5 m and the systematical error 0.5 meter. There was a stronger correlation for plots dominated by Norway spruce compared to plots dominated by Scots pine.

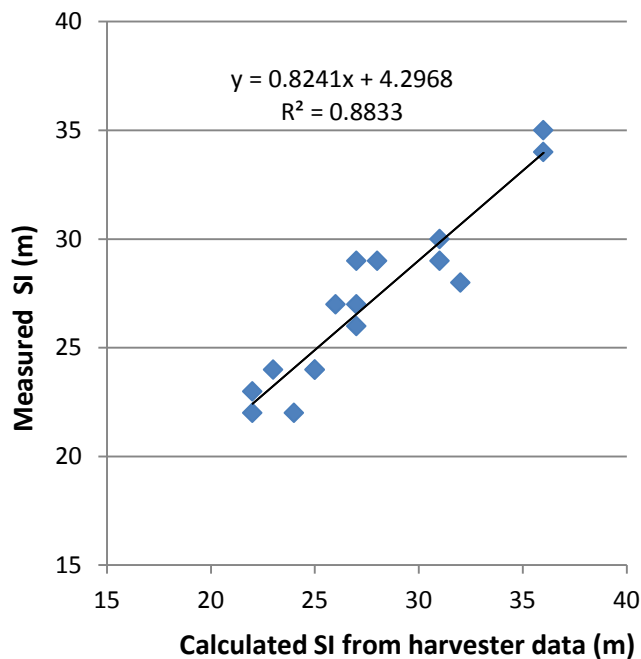


Figure 4. Site index (SI) calculated by using harvester data compared to site index measured manually.

Discussion and conclusion

Bio energy calculation

According to the result of the different biomass function, an adaptation of the Marklund functions has been made for different parts of Sweden. The results show that there is a high correlation between estimation of bio-energy quantities by harvester data and corresponding measurements at the heating plants. The results also show that geographical information is very good for planning forwarding of forest fuel and also to guide the forwarder in the daily work. The system is presently being introduced in Sweden and will be used in operations during 2011.

Site index calculation and other uses

The analyses of using harvester data for calculating the site index has showed very good result. This method, as well as other possibilities, for example area calculation and evaluation of thinning, is now tested in Sweden. To improve estimations of site indices it is also important to measure stand ages and feed the system with this information.

Other improvements for general use of harvester data for updates of forest plans is to move the position of the received GPS coordinates from the harvesters cabin to the actual positions of the harvester felling head.

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FIRST: Forest - Industry Research School on Technology - a joint Swedish - Finnish initiative to strengthen competitiveness in forestry

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Introduction

In order to stay competitive up to 2020/2025 it is estimated that the overall productivity in Nordic forestry must increase by a minimum of 50% compared to today's level. This includes improvements of the cut-to-length system, the need for mechanization in silviculture and development in forest energy operations. Applied technical R&D will play a fundamental role in the development of the next generation of forest operation systems. The present shortage of researchers trained in Forest Technology has been identified as a severe bottle-neck in those efforts.

The Swedish forestry sector has initiated the PhD program FIRST (Anon 2010). Swedish and Finnish parties of interest (SLU, Skogforsk, University of Eastern Finland, University of Helsinki, Metla and Metsäteho) have started the program. FIRST will, during 2009 – 2013, address the problems and build new capacity for qualified R&D and innovation. In this industrial PhD program, a number of researchers will be educated to take on future key positions in the forest research society as well as in the operational business sector, thus providing research and purchasing competence for the future. The co-operation with operating enterprises as industry hosts in both thesis work and practice enhances the relevance and application strategy of the effort.

PhD projects in FIRST

The PhD projects, listed below, were chosen in close cooperation with the forestry sector. Each project is then further specified in dialogue between supervisors, student and host company representatives.

Tree harvesting on soft ground (Jeanette Edlund)

The aim is to determine and improve bearing capacity, and thus accessibility, in stands on soft ground. Also, new technology will be compared with best practice of today. Host company: Sveaskog.

The effect of supply chain interactions on forest operations efficiency (Mattias Eriksson)

The aim is to investigate the efficiency and effectiveness in logging and transport operations and to identify possible areas of improvement in the wood supply chain. Host company: SCA Forest.

Productivity development in entrepreneurship forestry (Emanuel Erlandsson)

The aim is to map present business models for logging services in Swedish forest owners' organizations, and to identify possibilities for improvement in developing models tailored for specific organizational needs. Host companies: Mellanskog and Norrskog

Silvicultural technology (Back Tomas Ersson)

The aim is to study and analyze machines and systems for mechanized tree planting. Host company: Södra Skog.

Energy efficiency of forest machines (vacant)

The aim is to improve the energy efficiency of forest machines, with focus on the power train transmission. Host Company: Holmen Skog.

Human-machine interaction in mechanized forestry work (Carola Häggström)

The aim is to study the interaction between the human (operator) and the forest machine, or rather the system of the human and machine in conjunction. Host company: Skogforsk, through the SLO fund.

Productivity development of roundwood harvesting - forest machines as an information platform (Jussi Manner)

The aim is to increase the productivity of extracting roundwood with forwarders, exploiting the digital chain of information further. Host Company: Stora Enso.

Efficiency, applicability and implementation of new forestry transport systems (Gunnar Svenson)

The aim is to improve productivity and reduce fuel consumption in secondary haulage of roundwood. Host Company: Skogforsk.

Stump Harvesting (Simon Berg)

The aim is to develop new knowledge and technology for stump harvesting and to analyze various systems of stump harvesting with focus on productivity and environmental impacts. Host companies: Skellefteå Kraft and Jämtkraft.

Harvester-forwarder working process chain (Lasse Tikkanen)

The aim is to develop and optimize the harvester-forwarder working process chain at stand level. Host Company: John Deere Forestry.

Energy wood and pulpwood from young stands (Aaron Petty)

The aim is to increase the competitiveness and procurement potential of energy wood and pulpwood from young stands. Host Company: Metsäteho.

Forest fuel supply chains (Johannes Windisch)

The aim is to optimize forest fuel supply chains using modern ICT and logistic systems. Host Company: Metla.

Discussion

The establishment of a joint Finnish-Swedish research school in Forest Technology will create long-term beneficial impacts by developing cross-border synergies, networks and critical mass in research work. The co-operation with operating enterprises as industry hosts in thesis work and practice will enhance the relevance and application strategy of the effort. In addition to research work and courses, PhD students will go through one year of advanced professional practice at the host company.

After the project is completed, doors will be open to either a continuation within science or in the forestry sector. Ideally, about half of the doctors-to-be will continue within academia after the research school is finished and half will continue as technical strategists in the forestry sector. One of the most important parts with FIRST is to create an international scientific environment and strengthen the international network. Although FIRST does not represent a large research school, it is probably the largest group of PhD students in the area of Forest Technology world-wide.

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Session 2

Man and Machine Interactions

Chaired by: Walter Warkotsch & Maryse Bigot

Long-term productivity's correlation with short-term performance ratings of harvester operators

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As presented at the FEC conference.

Managing ergonomics for better health and increased efficiency in forest operations

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Context and objective

A great deal of knowledge about healthier, and thus more economic and efficient working practices, has been generated over the last decades. The challenge now is to implement it in practice within the context of forest operations.

In order to process this information about ergonomics into forms and procedures that meet forest SMEs' demands, the principle aim of the European COMFOR project (2006-2009) was perceptions and learning culture.

Materials & methods

The COMFOR project was carried out as both a novel iterative and a collaborative development between researchers from universities, applied research centers, and forestry contractors, who were supported by their associations under leadership of the European Network of Forest Entrepreneurs. In total, 21 partners from 10 European countries were involved.

As a first step, the handbook "Health and Performance in Forest Operations" and its participative methodology, tools and checklists have been introduced to ten forestry contracting companies, from ten different countries, by partners from the applied research centers. The handbook and its related endeavors were a result of the European Project, ErgoWood (2002-2005). The aim of this operation was to investigate if and how enterprises were capable and interested in working with such instruments. The ten enterprises were very different in terms of both the numbers of employees (2 to 40) and their activities (from motor-manual harvesting to mechanized harvesting through chipping, in association with wood haulage or not, etc.).

Experience gained from these ten case studies made it possible to precisely determine contractors' expectations for tools and management methods for ergonomics within their companies. On this basis, researchers began to re-design the ErgoWood tools and to develop new ones. The content and the format have been discussed between researchers and contractors. The new tools have then been tested by the ten contractors with their employees and the collected feedback was used to refine the tools for their final version.

In the final step of the project, along with communication activities, staff from various organizations providing services to forest contractors (training centers, consultancy companies, health and safety authorities, contractor association staff, etc.) who have been

trained to use and apply the COMFOR package. More than twenty training sessions have been organized in the ten countries.

Results

The COMFOR package is specially customized for forestry contractors. It provides contractors and their teams with guidance on how to improve and maintain operators' health, safety and well-being. It is composed of a guide for continuous improvement of ergonomics management in forest SMEs (The Process) which illustrates the application of seven user-friendly management tools as follows:

- (1) Monitor the operator's health and performance (Health and Performance Check),
- (2) Monitor and estimate hidden costs related to illness (Cost/Benefit Check),
- (3) Monitor mental strain, organization and working climate (WORX for SMEs),
- (4 & 5) Identify contractors' and operators' qualification needs (Skills check),
- (6) Assess the ergonomic condition of machines (Ergo Check),
- (7) Assess an operator's sitting posture (Sitting check).

Tools numbered 1 to 3 are composed on a questionnaire (to gather data) as well as an excel file for processing the data, showing results and recording decisions. Tools numbered 4 to 7 are more user-friendly 2 page-checklists.

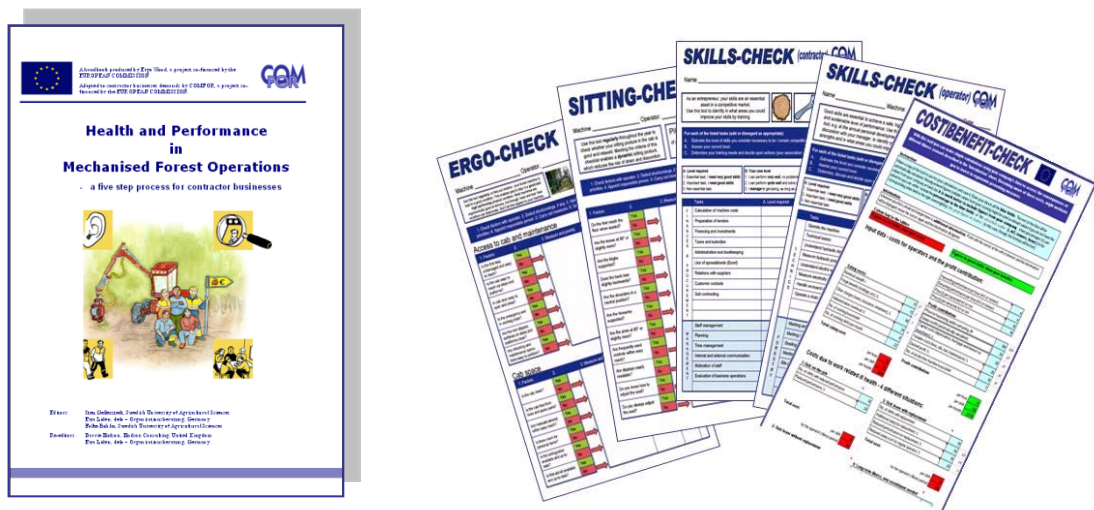


Figure 1. COMFOR package - examples of views

Each tool can be applied individually, but it is recommended to use the full set in the development process for the enterprise.

The tools, the processes and also explanation and instruction materials for contractors and trainers, are available in 9 different languages at www.enfe.net/comfor.htm.

Discussion and conclusion

Training sessions and other dissemination activities carried out at the end of 2008 and beginning 2009, proved that the acceptance of the COMFOR package is high. The main objectives were either the integration of contractor and operator training and certification plans or the integration of the tool box for the health and safety experts who provide assistance to the contractors.

Nevertheless, the fact is that contractors are generally so busy with their day-to-day struggle for productivity and client satisfaction that ergonomics are typically not the priority. This is especially true during a period of economic crisis, such as at the end of 2010.

Yet, most of the contractors do not have a clear view of the increased cost and impact of illness on the enterprise's economic performance. In such a context, the Cost/Benefit tool is of a particular interest to increase awareness of the benefit of considering ergonomics. This tool supports calculations for four common sickness situations:

- (1) The operator is working though feeling ill (performance is reduced);
- (2 & 3) The operator is temporary on sick leave and no replacement is available (the machine stands still) or a replacement is found (but extra costs are generated and performance is reduced);
- (4) The operator is so ill that he has to quit forestry (recruitment is to be undertaken).

When contractors read the result of such calculations, they generally become aware that they should deal with men as they deal with machines; it is more efficient and less expensive to do maintenance and preventive actions than waiting for the breakdown or the illness.

Lastly, even though the aim of the COMFOR package was to reduce complexity as much as possible, many contractors consider it useful to have professional support simply because they are not familiar with participative management methods. This confirms the important role that contractor associations or other organizations close to forest contractors can play in favor of better ergonomics and performance in forest operations.

Keywords: ergonomics, forestry, work organisation, performance, forestry contractors.

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Accidents and near accidents in mechanized forestry work in Sweden

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More than ninety percent of harvesting operations in Sweden are performed by specialized machine operators in a complex and varying work environment. Simultaneously, demands on productivity and work quality are high and constantly rising. Thus, the system of the human and machine in conjunction is crucial for keeping the business productive and safe. Accidents are not only costly for the individual and the company but also to society at large. To provide a better understanding of how to prevent further accidents, better knowledge of the occurrence and nature of accidents is needed. Therefore, a mail survey was conducted directed to a sample of 1131 machine contractors and 388 company employed machine operators, with response rate of 52% and 49% respectively.

Results

Average working time for forest workers in mechanized forestry in 2009 were 1194 hours, whereof 969 hours were directly connected to machine work. Of those were 46% spent in harvesting, 40% in forwarding and 7% in maintenance and relocation to new site (Figure 1).

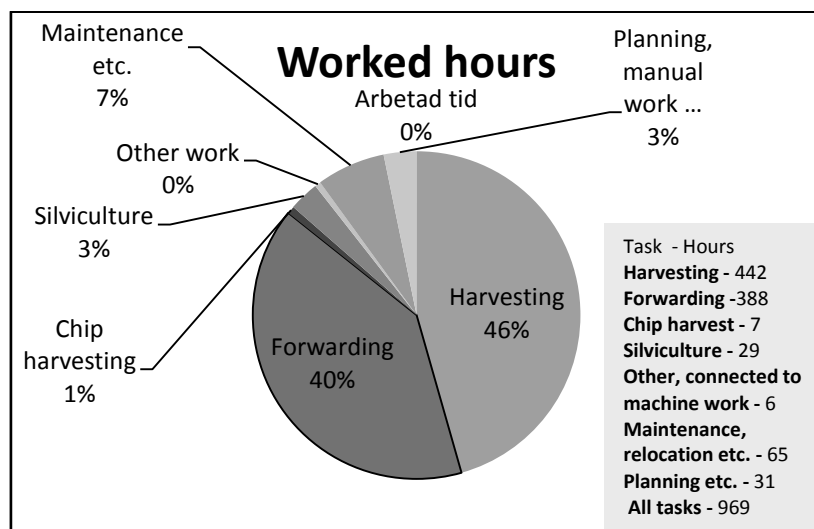


Figure 1. Distribution of worked time by task in mechanized forestry

Twenty two accidents resulting in sick-leave per 1000 gainfully employed were reported (Table 1) corresponding to 2 accidents per 100 000 worked hours (Table 2). Results further show that 35% of accidents occurred in harvesting, 32% occurred during maintenance (24%) and relocation (8%), and only 5% in forwarding. Twenty eight percent of all accidents occurred in other tasks connected to machine work and 7% in entrance and exit of the machines. When accounting for working time in different tasks maintenance and relocation has a prevalence of 11 per 100 000 worked hours, this is six times as frequent as in harvesting.

Table 1. Accidents resulting in sick-leave per 1000 gainfully employed

Accidents/1000 employees			
Task	All	Company Employed	Contractors & Employees
Harvesting	8	22	5
Forwarding	1	0	1
Chip harvesting, silviculture, etc.	0	0	0
Maintenance	5	11	4
Relocation	2	8	0
Planning etc.	0	0	0
Other work close to machine	4	6	4
Entrance/exit	1	4	1
All tasks	22	52	16

Company employed reports 52 accidents per 1000 employed, or 8 per 100 000 working hours, whereas machine contractors reports 16 per 1000 employed respectively 2 per 100 000 hours. Harvesting constitute 43% of accidents amongst company employed and 29% amongst contractors. Thirty seven percent respectively 28% of accidents occurred in maintenance and relocation to new site. Twenty seven percent of accidents amongst contractors occurred in other tasks close to machine work, whereas those tasks only contribute to 11% of the accidents amongst company employed.

Table 2. Accidents resulting in sick-leave per 100 000 worked hours

Accidents/100 000 worked hours			
Work task	All	Company employed	Contractors & employees
Harvesting	2	3	5
Forwarding	0	0	2
Chip harvesting, silviculture, etc.	0	0	0
Maintenance, etc.	11	15	33
Planning, manual work, etc.	1	0	5
All tasks	2	8	2

Maintenance is the most accident prone task with 15, respectively 33 accidents per 100 000 working hours for company employed and contractors, when accounting for working hours. Harvesting is the second most accident prone task, whereas planning and manual work (5 per 100 000) as well as forwarding (2 per 100 000) also appear to be a risk amongst contractors and contractor employees.

Discussion and conclusions

The large numbers of accidents leading to sick leave in this study supports findings in previous studies (Lindroos & Burström, 2010; Pinzke & Lundqvist, 2006) arguing that accidents in official records are underreported. Another implication in relation to official statistics may be that machine operations encompass more accidents than many other occupations in forestry.

The large number of sick leaves in machine operation compared to maintenance is partly explained by the greater amount of time spent on machine operation. Previous research has stated maintenance as the highest risk in mechanized forestry (Väyrynen, 1982). This is not contradicted, but measurements must be directed both towards the harvesting situation,

where we have the highest numbers of accidents, and maintenance where we have the highest frequency. Further is entrance and exit to the machines carried out several times a day, and the seven percent of accidents in this phase points to a much higher risk accounted for by time unit.

Based on these findings, further accident investigations will be conducted with the aim of identifying critical causes contributing to these safety problems on multiple levels (human, machine and organizations).

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Modeling the ride comfort of a forwarder

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MSc Thesis

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As presented at the Fourth Forest Engineering Conference.

Training of operations management and machine operators – a way to increase forest fuel value and decrease operational costs

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Objective

In Sweden, forest energy is priced by the net effective (lower) heating value. Thus, the price of fuel increases with decreasing moisture and ash contents. Rainy summers and snowy winters may lead to unsatisfactory dry matter content. The diagram (figure 1) below shows upper and lower quartile for dry matter content in forest fuel delivered 2008 in northern Sweden. The wide span between the upper and lower quartiles indicates that some batches of forest residues have been poorly stored and handled.

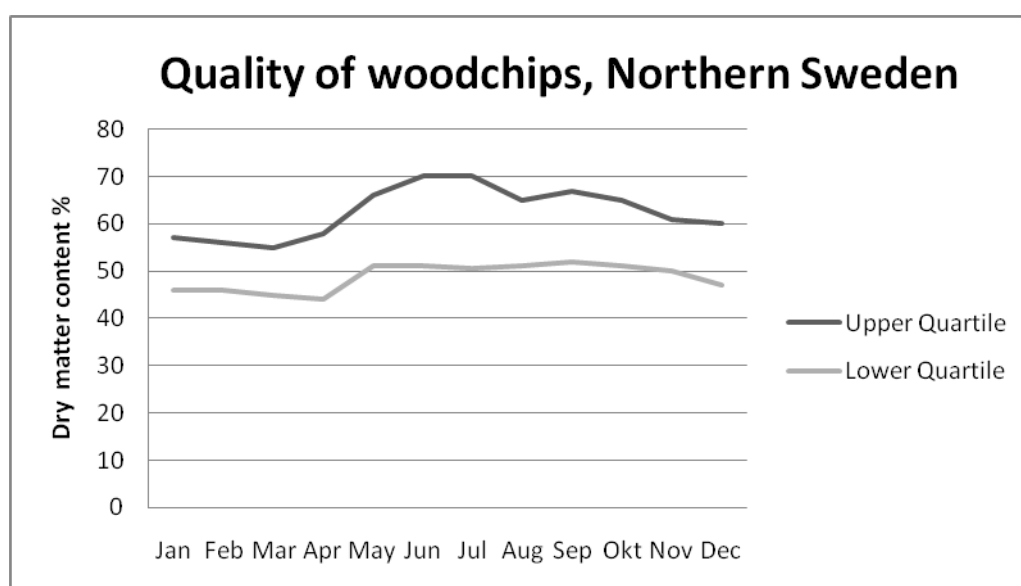


Figure 1.

During the last decade use of forest fuel has increased dramatically. With rapidly increasing demand for forest fuels follows a growing number of people involved in residue extraction. It is crucial to transfer necessary knowledge and skills in order that everyone understands what to do and how it will affect the total result and/or other people in the chain. Hence, training of operators, planners, and operations management becomes important. The benefit of educational investments was clear in a Swedish campaign and since April 2008 Skogforsk has been giving courses in residue extraction and handling.

Aim

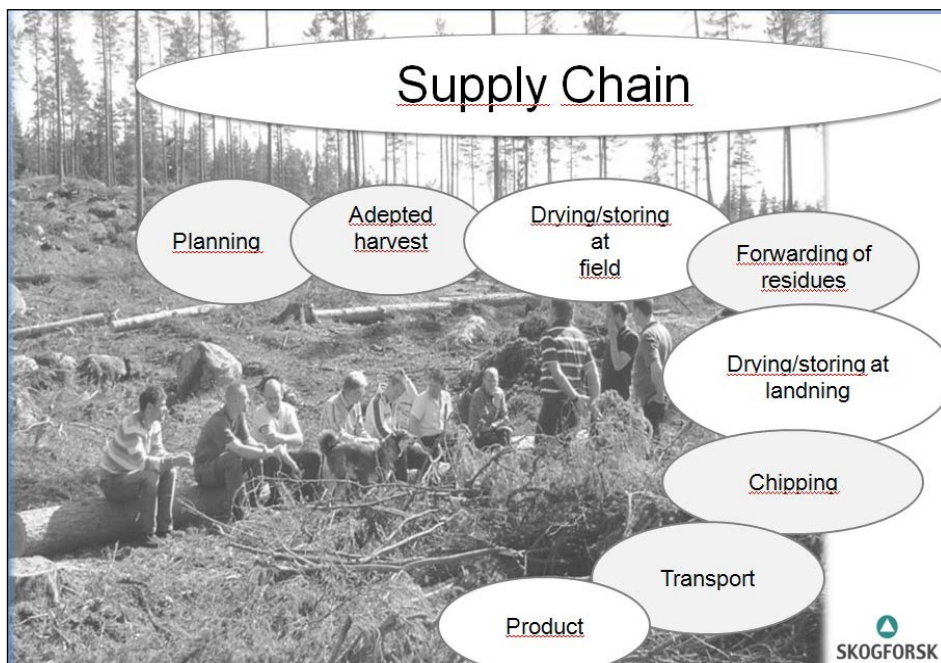
The aim of the courses was to increase the energy content of extracted material and to decrease the production cost.

Material & method

Each course was adapted to the client company's local conditions, logistic possibilities and existing extraction methods. Part of the strategy is technology transfer through sharing 'state-of-the-art-solutions' from regions with long experience of residue extraction to areas where production is starting. The course gives an overview of demands and possibilities for different extraction systems and advice of how to improve feedback and communication within the organization. The methods used within the company are discussed and benchmarked during

the courses, often resulting in modified workflows and use of better technical equipment.

The courses are conducted as seminars for planners and management, and as seminars and sometimes practical instructions for machine operators. During April 2008 – December 2010 more than 1800 people was trained. Of those more than 1000 were officers within operations management and planning.



Picture 1.

The courses held by Skogforsk have been aiming to simplify communication and to increase commitment between all tiers of the supply chain, including machine operators, planners, and middle management.

Result & discussion

Through the short initial courses and continuing information and training afterwards, participating companies estimate that they have reduced production cost by 5-10% while increasing biomass value. Larger margins allow increased revenues and profitability for all stakeholders in the forest residue production chain. The end-users receive a cleaner fuel, which improves their efficiency and reduces the risk for technical disturbances.

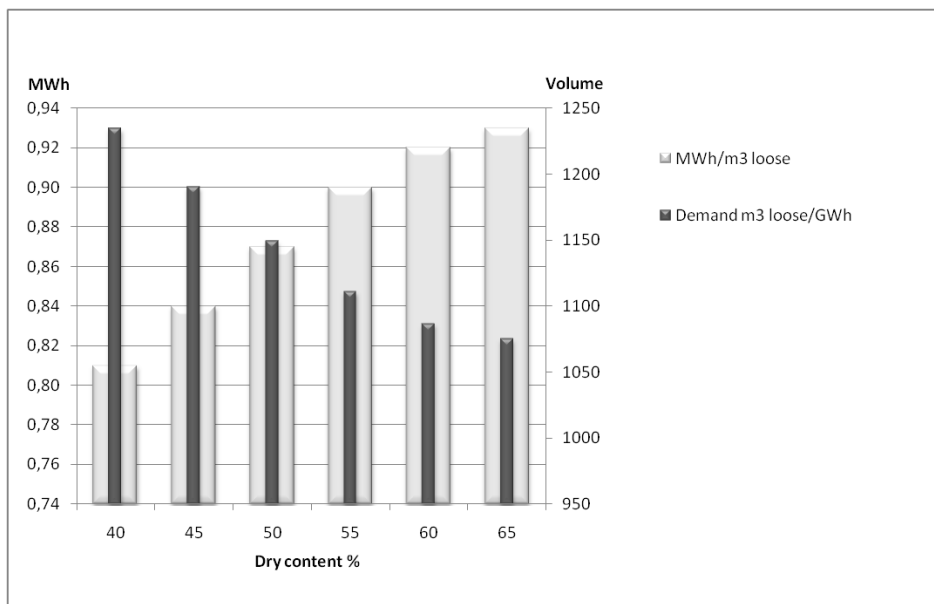


Figure 2. The diagram shows the relation between net energy content of woodchips per m3 loose (wide staples), and the volume needed (thin staples, m3 loose) to deliver 1 GWh.

By introducing routines for communication, self-control systems, quality-checks and by highlighting the role of each single operation in optimizing the dry matter content of the delivered material, the average dry matter content of the participating companies is estimated to have improved by approximately 5 percent. Another benefit is that this will reduce the volumes needed to fulfill their contracts (figure 2). Finally, improvements of final felling method used may cut costs of subsequent steps of residue handling, e.g. resulting in both lower forwarding and chipping costs.

The reported economic improvement, + 5-10 percent, is not easy to confirm from a scientific perspective, largely due to the difficulties in validating historical production statistics of participating companies. Also, average transport distances have increased as a result of growing demand for forest fuels.

The courses also focus on content of soil and other contaminations of the fuel. Purity is of large importance because of the ash content and to avoid technical disturbances for the end customer, as well as for avoiding high repair and maintenance costs for the chipper. To achieve a pure, high energy fuel the whole value chain must interact.

Conclusions

Quality parameters

Clear and defined quality assurance has a major impact on the total production cost as well of the total revenues of the delivered forest fuel. In the establishment phase, education, training and enhancement of staff's 'supply chain awareness' was well worth the investment, according to the experience from the training program described in this paper.

Improvement over time.

So far, participating companies report improvement in the span of +5 -10 percent one year after the courses. As with most campaigns, there is a risk that performance will decrease with time. This can be counteracted by introducing a proper policy in the company to keep their employees up to date and by repeated educational initiatives in the future.

Finally

With the current low profit margins of forest fuel recovery, the question is not if training is needed, but rather if anyone can afford not to do things correctly?

Sources:

Johannesson 2008, Efficient Residue Extraction, Instruction

Workload benefits of using synthetic ropes in cable yarder rigging in Norway

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This paper presents the measuring equipment, techniques and results of a study monitoring the work strain experienced by cable logging crew members while drawing out the strawline during uphill rigging. It also documents the benefits of using a light weight synthetic strawline as opposed to the conventional steel wire strawline. The aim of the study was to quantify the resultant difference in workload.

A 300m yarding corridor was used in testing two subjects selected from a logging crew. The trail was registered with a GPS and profile inclines and distances recorded with a Vertex range finder/clinometer. Three treatments were defined; synthetic rope (SYNT), wire rope (WIRE) and no load (ZERO). The ZERO load treatment was used as the basis for comparison.

Walking velocity was recorded at 25 m intervals using SIWORK time study software on a Husky Hunter datalogger. Each subject did 3 repetitions for each rope type, with approximately 1 hours rest between circuits. For the first trip, the choice of cable was randomized and an alternating pattern was subsequently followed. The rope was attached to the subject with a 300 N load cell (accuracy 0.1 %), fitted with a wireless transmitter which allowed for continuous logging of the tensile force in the rope. The transmitter had a range of 200m.

Heart rate was measured as a proxy for work strain using a Polar RS400 pulse monitor with continuous data logging and storage. Heart rate data was superimposed with the continuous tension measurements and the digital terrain model.

Results showed that pulling the synthetic rope considerably reduced the total work energy requirement (J) - a difference equating to roughly 2 normal working hours for a crew member when using the definition of heavy physical work (5-7 kCal min⁻¹) (fig 1).

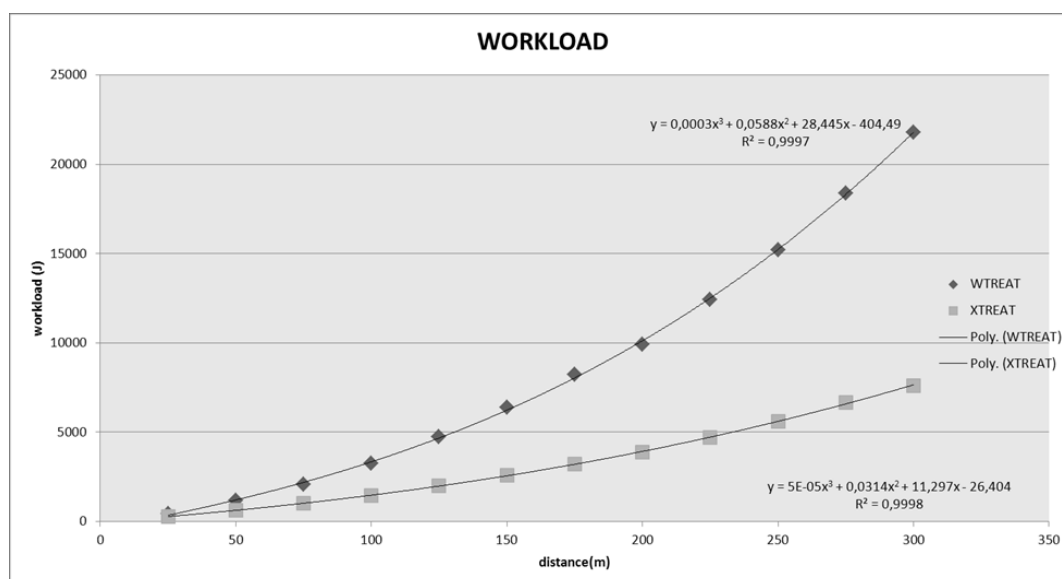


Figure 1. The difference in workload required for pulling out the wire and synthetic ropes respectively.

Heart rate differences between the three treatments were only significant for 1 of the subjects, indicating a higher work capacity and probably a better ability to adjust effort to the workload. Depending on the frequency of rigging and the availability of labor, the interpretation of benefits from these results varies.

Keywords: cable yarding, rigging, work strain, synthetic ropes

Tools for the study of human machine interaction

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The performance of a state-of-the-art forest machine is generally not limited by the mechanical performance but by how the operator manages to utilize it. To fully benefit from the performance of the machines of today and in the future it is necessary to better understand the human machine interaction (HMI).

Skogforsk has started the development of a methodological toolbox, adapted to the study of HMI and mental workload in forest machines. It contains physiological and subjective methods and gaze tracking. Physiological measures, e.g. heart rate variability and blink rate, are indicative of mental workload. Subjective methods, e.g. NASA-Task load index, reveal how the operator perceives the load and can be used to diagnose its origins. Gaze tracking is used to study how the operators gather information from the environment and computer interfaces.

The aim is to gain insight into the cognitive processes of the operators as well as to find useful quantitative measures of mental workload. With this set of methods we will be better suited to evaluate future innovations in forest machines that affect the human machine interaction.

The methods will be used in a series of pilot studies in The Troedsson Forest Technology Lab at Skogforsk as well as in real machines. Subjects that will be studied are, for example, visual behavior in different conditions and bucking computer interfaces, and the effect of automation and of multi-tree handling on mental workload.

State-of the-art and the results of these studies will be presented at the 4th FEC conference.

Sustainable work related muscle activity patterns among forest machine operators

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Background

Several investigations have shown that the prevalence of musculoskeletal disorder is high among forest machine operators. The ergonomic design of workplaces is important in the prevention of work-related musculoskeletal disorders (1). In mechanized forestry, neck pain and sick leave among forest machine operators working with extremely pronated hands have been reported (2). We wanted to investigate if the ergonomic design of the harvester workplace could be related to differences in neck pain.

Our hypothesis was that different ergonomic construction of control levers in harvester brands could give exposure to different level of static muscle work, disposing for neck pain.

Material and methods

Timberjack and Valmet harvesters were chosen for the investigation. These brands show clear differences in several construction details of possible ergonomic importance. In the Timberjack harvester, the control lever operation is often a combination of using small joysticks with the fingertips and a keyboard designed to be operated like a piano with the palm of the hand in a horizontal position. In the Valmet harvester, most functions are gathered in large joysticks where the palm is used in a vertical position and the hand grasps around the stick and the fingers press the buttons like an accordion. The ergonomic difference between these two designs is that the hand/fingers in the Timberjack shift between a horizontal and vertical position while in the Valmet the work load will be only in the vertical position of the hand. On both vehicles the cabin can be rotated 360 degrees, but on the Timberjack the crane is installed directly on the chassis, while on the Valmet it is either in the middle or on the right side of the cabin. As a consequence of the design, the body postures for the operator in the Timberjack will involve increased twisting of the head to follow the movements of the crane, while in the Valmet no such extra movement is necessary.

From a broader study of 39 forest machine operators driving several brands of vehicles, operators driving Timberjack (n = 7) and Valmet (n = 6) were selected. Muscle activity was continuously measured during a whole working day. Surface electromyography (sEMG) was used for this purpose and the amplitude and frequency parameters in the right and left upper trapezius muscles were recorded. A period with sustained low-level muscle activity (SULMA period) is defined as a period with continuous (without interruptions) static muscle activity above 0.5% EMG_{max} for 1.6 s or longer (3). The number of SULMA periods was calculated and analyzed for both right and left neck muscles in ten predetermined intervals: 1.6 – 5 sec, 5 – 10 sec, 10 - 20 sec, 20 sec - 1 min, 1- 2 min, 2 - 4 min, 4 - 8 min, 8 -10 min, 10 - 20 min, and greater than 20 min. The number of SULMA periods was also expressed in cumulative periods above the minimum value of the already predetermined ten intervals. Discomfort/pain in the neck was rated within five categories according to the Standardized Nordic Questionnaire: 0 days, 1-7 days, 8-30 days, more than 30 days and daily (4). The scale was also dichotomized into categories with pain ≤ 30 days (0) and pain >30 days.

Results

The operators in the Timberjack showed a significantly higher number of SULMA periods with short duration in the *right upper trapezius muscle* compared to the Valmet operators (Fig. 1a). The Valmet operators had significantly more SULMA periods > 10 min duration per hour compared to the Timberjack operators (Fig 1b) in the *left upper trapezius muscle* (5). A slightly higher amount of Valmet operators reported neck pain > 30 days compared to the Timberjack harvesters (non-significant).

Conclusions

This study showed that operators driving Valmet vehicles had a significantly higher number of periods with sustained low-level muscle activity (SULMA) above 10 min duration per hour in the left upper trapezius muscle and the same tendency in the right. A higher level of static muscle activity and less muscle rest were also found among the Valmet operators in the same two muscles. This finding may be explained by the more fixed postures in the Valmet vehicle. The increased number of cumulated long SULMA periods among the Valmet operators was explained by the hand/wrist in work postures being either pronated or supinated in a vertical position during control lever operation. The higher exposure of low level muscle activity found in the Valmet brand indicate a possible higher probability of developing muscle pain in operating such kind of control lever.

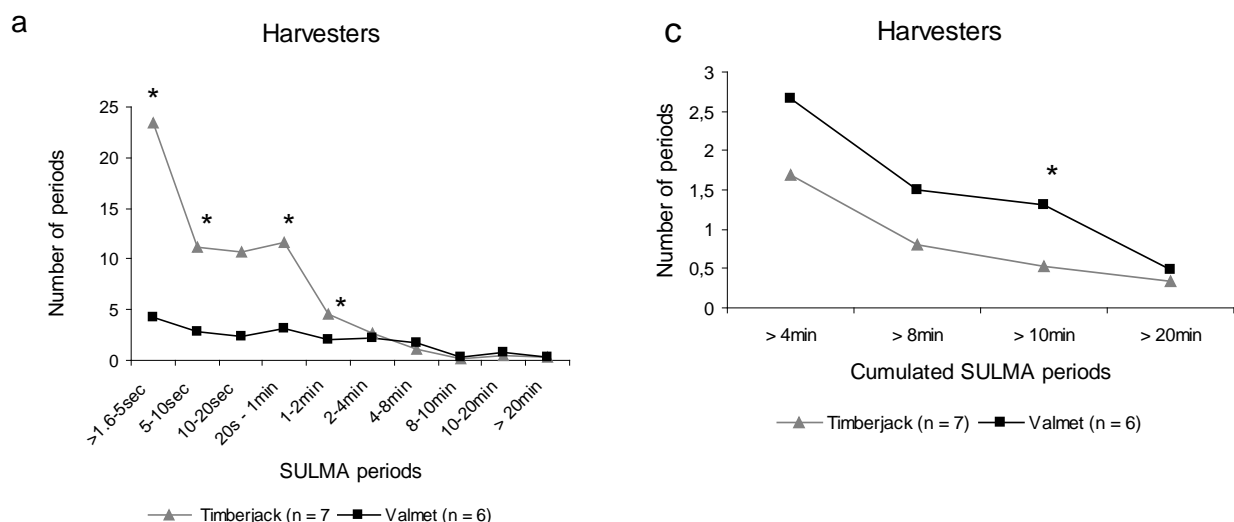


Figure 1 Mean number of periods with sustained low-level muscle activity (SULMA) in the *right upper trapezius muscle* among machine operators operating control levers while driving Timberjack and Valmet harvesters (a) and mean number of *cumulated* SULMA periods in the *left upper trapezius muscle* (c).

Keywords: sustained low level muscle activity, control lever, machine construction

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Session 3

Harvesting Systems Development

Chaired by: Kjell Suadicani & Dirk Laengin

Development of optimal multi-tree felling equipment

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Efficient accumulation is important in all multi-tree felling equipment. The productivity of multi-tree handling felling heads is affected by the degree of accumulation, by tree size and by density of removal. If two trees are handled per cycle, crane movement ideally decreases by 40 percent/tree. Due to the nature of the work, time savings stagnate with additional accumulation; however, this is partly an effect of shortcomings with the accumulation devices and because maneuvers become unwieldy. Further, operator skill level and choice of method are important determinants of performance.

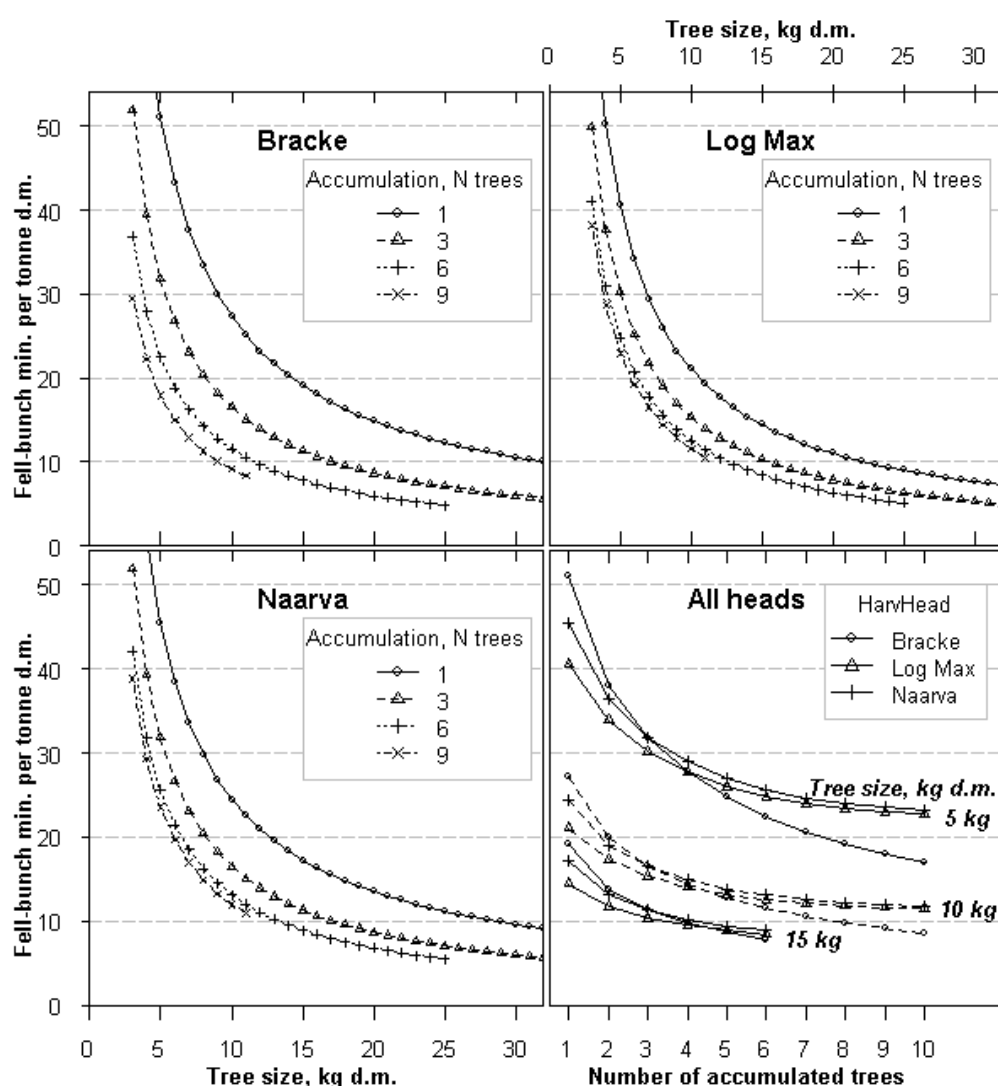


Figure 1. Time consumption per production unit with increasing degree of accumulation and increasing tree size for the different heads.

Accumulation appears to substantially increase the productivity of the fell-bunch cycles. The time-saving through accumulating two trees is circa 20 percent for harvester heads and 25

percent for felling heads with circular saw, while the time-saving by accumulating 10 trees was some 50 percent for harvester heads, and close to 70 percent for felling heads with circular saw.

In the lower right figure in figure1, we can see that for tree sizes less than 10 kg DM the disc saw (Bracke) is the most productive head. The continuous rotating disc saw provided the possibility of consecutive felling and accumulation without fixing each tree in the felling head before cutting from the stump. To fully utilize this possibility, the operator has to be skilled as the timing of closing the grapple is crucial to avoid the recently felled trees to drop out of the head.

In early thinning stands (17-20 kg DM, tree height > 10 m) the harvesting productivity is about 30% higher for the harvester head compared to the disc saw felling head. With many long stems to handle in each bunch, the harvester head benefited from the feed rollers, which made the work connected to bunching, and especially bucking, more easy and efficient because the tree bunches did not get stuck in surrounding tree crowns even when handling many trees simultaneously.



Bracke C16.a felling head.
Photo: Maria Iwarsson Wide.



Log Max 4000 B harvester head.
Photo: Helmer Belbo

Figure 2. Picture of the felling heads and the harvester head used in the study.

Accumulation has proved to be an efficient means to increase the productivity of small-tree harvesting, but studies also points out possibilities for further improvement of both the harvesting equipment and the work methods. Looking to the observed accumulation in figure 1, one can see that the average degree of accumulation typically is approximately 50 percent of the accumulation capacity. This means that in 50 percent of the crane cycles, the degree of accumulation is below 50 percent of the accumulation capacity. This could possibly be improved if the work instructions were modified, from strict selective quality thinning towards less strict regimes. For example, smaller trees with limited harmful effect on neighbor crop trees could be left in the stand if they were not easily available during the felling of other more competitive trees.

The disc saw felling head shows occasional problems with keeping the tree bunch fixed in the head, and with pulling the tree bunch to the ground between remaining trees. The frequency of these troublesome crane cycles could be possibly lowered by improved design of the heads and by modifying the work method. The rotation speed of the disc saw can be considerably reduced when cutting larger trees. The operator then has to wait a moment for

the disc to regain rotational energy before next cut. Optimizing the currently rather short distance between the grapple and the accumulation arms is another improvement that needs to be made. Likewise, the sequence of which the target trees in the work zone are felled could be essential to avoiding the tree-crowns getting stuck to each other when bunching the trees. For example, the design of the grapple could be important as it affects how easily the piles of sprawling trees are collected into the grapple for bucking.

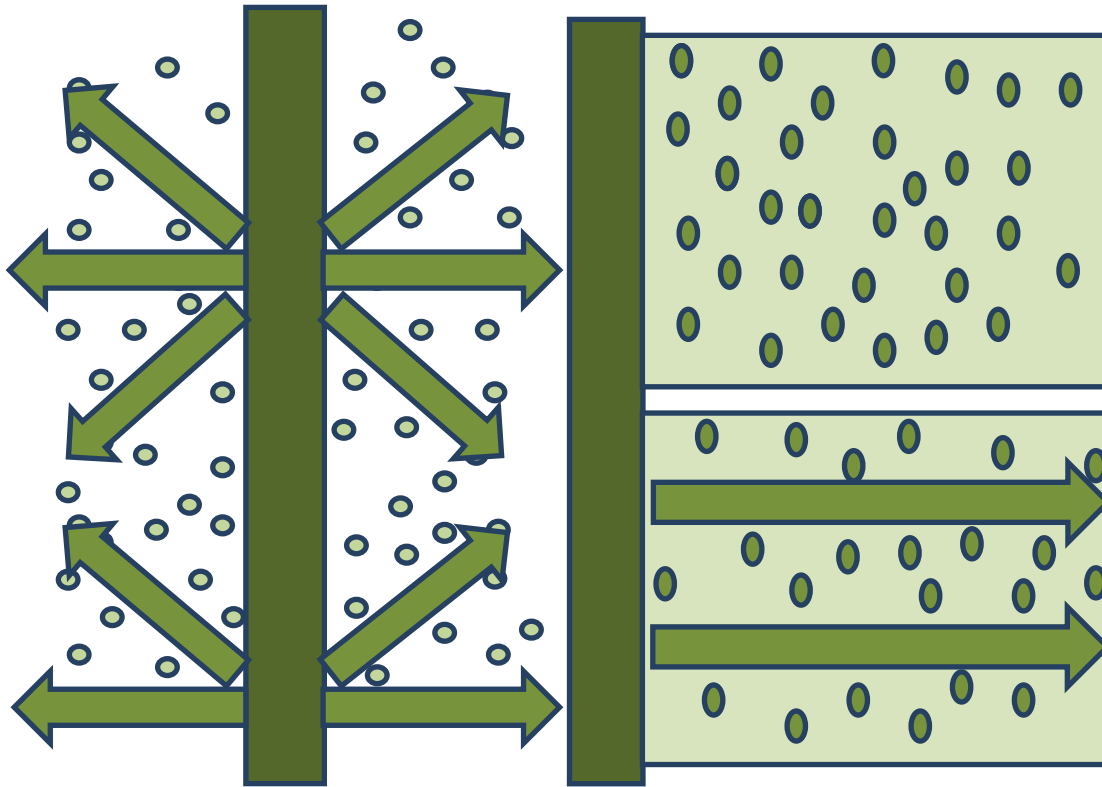


Figure 3. Geometrical working principles in small dimension stands.

The harvester heads seems to be more stable in all the crane cycle work elements, but there are occasional problems with the bunch-feeding. This observation indicates that efficient multi-tree feeding is important as a mean to further increase the efficiency of multi-tree harvesting for harvester heads.

Improved technical design and modified working methods are thus needed to fully utilize the potential gain of multi-tree felling equipment. Some conclusions from the ongoing projects are listed as follows:

- Fairly large heads are needed to ensure stability of the accumulated tree bunch and to allow for high volume/crane cycle.
- Expedient and precise crane movement place demand on powerful and stable base machines, which also improves operator working conditions.
- Feed rollers simplify bucking and piling of tree bunches, especially when tree heights exceed 7-8 meters, but multi-tree feeding needs to be further developed.
- Continuous harvesting and accumulation/compaction is needed, especially for efficient harvesting of the smallest dimension stands.
- The practical degree of accumulation typically reaches half the theoretical capacity, indicating shortcomings of the technology and/or method.
- Geometrical thinning may simplify the work and boost productivity by allowing continuous accumulation and a working pattern with minimized crane movement.

Keywords: Biomass harvesting, young stands, multi-tree handling, accumulation

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Forces required to vertically uproot tree stumps

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Introduction

Over time, stumpwood has been harvested by a multitude of techniques for a number of purposes, such as firewood, fiber board or pulp production, extraction of chemicals; root rot control and the facilitation of various kind of ground work (cf. Jonsson 1985). Stumpwood attracts renewed interest due to increased use of forest biomass for bioenergy. The harvesting of stumpwood after regeneration fellings could provide a considerable quantity of bioenergy since the biomass below stump cut (stump with attached root system) constitutes approximately 20% of the total living tree biomass, which exceeds the amount of logging residues (Hakkila and Parikka 2002). Stumps are uprooted with crawler excavators, which have strong cranes (ca. 400 kNm gross lift torque), but are not designed for moving in forest terrain. Their use is based on practical experience with available machine types rather than thorough examinations of requirements, partly due to limited knowledge of force requirements for uprooting of stumps (cf. Athanassiadis et al. 20xx).

The objective of this work was to quantify mean and maximum forces required to vertically uproot stumps of Norway spruce (*Picea abies*) and birch (*Betula* ssp.) together with the effects of various soil types and uprooting methods.

Material and Methods

The machine used was an SRG 160 Stump harwarder based on the cabin and crane of a Cat M316D excavator and a double bogie forwarder undercarriage. The machine's mass was circa 26 metric t and the crane had a reach of 8.1 m. The used crane-mounted 1.65 metric t uprooting device enabled comparisons between usage of solely crane force, and a method in which preparatory loosening forces were applied prior to crane force (Figure 1).

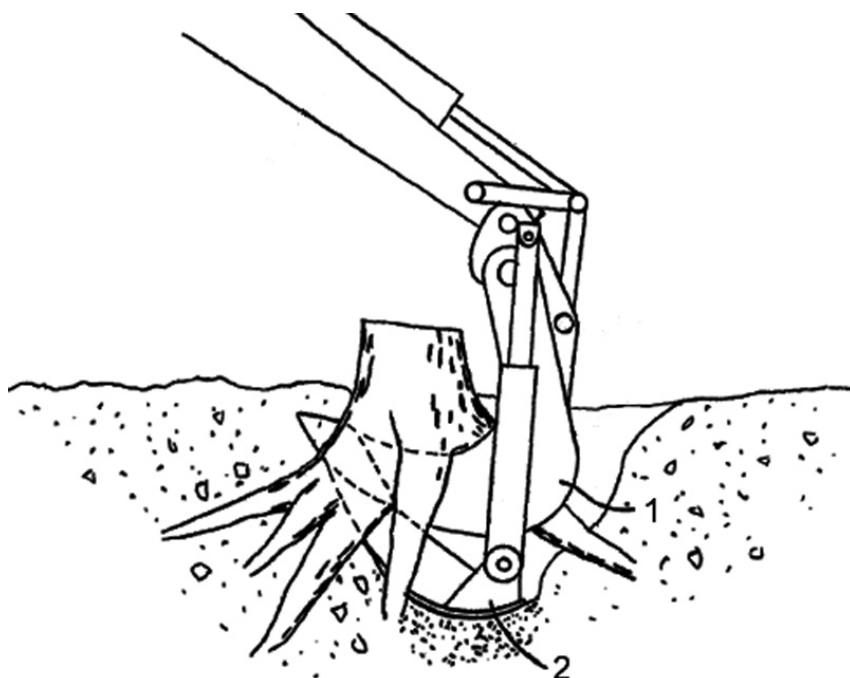


Figure 1. Sketch illustrating the technique for preparatory uprooting before applying crane force. The uprooting device (1 in the figure) is placed in the same position as when uprooting

with pure crane force. Pistons attached to a metal plate (2) jointed to the tip of the uprooting device are extended and, using the ground as a counterweight, the uprooting device and the stump are pushed upwards. Picture derived from Hedblom (1979).

When operating, the tool was placed around a stump as with similar conventional uprooting devices, but instead of using the crane immediately the plate could be used to loosen stumps by pushing the device upwards by extending the pistons with the ground as a counterweight. When uprooting with pure crane force, the operator just lifted the boom (without extending the piston in figure 1). The vertical force required to uproot stumps were derived from the law of levers and the force developed by the crane pillar lifting cylinders (calculated from the hydraulic pressure and cylinder diameters) (cf. Lindroos et al. 2010).

Results

Force requirements were similar across tree species, increasing curve-linearly with stump diameter, and stumps uprooted in a single piece required more force than stumps that split unintentionally. Preparatory loosening reduced crane force requirements (Figure 2) and, surprisingly, less force was required to uproot stumps from a mesic, till soil than from a moist, finer-textured soil. The maximum force required for uprooting of stumps with diameters 30 and 50 cm was close to 30 and 50 kN respectively (Figure 2).

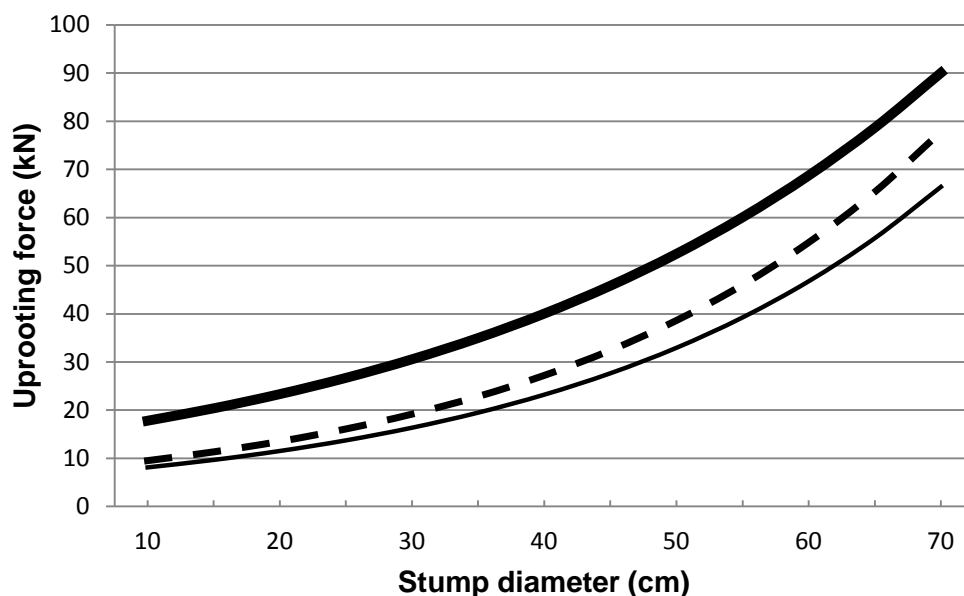


Figure 2. Uprooting force for stumps uprooted in one piece as function of stump diameter. Solid bold line = maximum force for spruce and birch, in general 97.5% of observations should be below this line. Dotted line = Average force spruce on moist soil and conventional method. Solid thin line = Average force spruce on moist soil and preparatory loosening method.

Discussion and Conclusions

The average force to uproot a spruce stump was estimated to 12 times the corresponding mass of the same stump. The method with preparatory loosening of the stump has theoretical possibilities to be much more efficient than the field results indicated. Functions for maximum force requirements (Figure 2) indicate that powerful harvesters and forwarders (gross crane lifting capacity of 273 and 155 kNm, respectively) should be able to uproot all stumps with ≤ 61 cm and ≤ 32 cm diameter, respectively at 3 meter reach, in one piece. Larger stumps could be managed if stumps are split before uprooting. However, the potential for conventional forest machines would increase if lighter stump harvest devices could be developed. The theoretical findings are consistent with indications from a few small-scale

practical applications of both harvesters and forwarders in Sweden and Finland (cf. Laitila et al. 2008).

Acknowledgement

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A stand typology for mechanization in hardwoods: the choice of the right logging machinery and method for the various broadleaved stands in France

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Context and objective

A consensus exists in France on the urgent need for developing mechanization for logging operations in hardwood stands in order to both face the lack of chainsaw operators and to realize increased harvest of hardwoods for energy use (Cacot and al., 2006),. However, the variation among broadleaved stands is so huge that it is not evident to know how what to do in practice: which machine should be used and in which type of logging operations? Based on this experience from many studies carried out during the last 15 years, FCBA developed a methodology:

- To help forest managers and wood supplying companies identify the stands they can mechanize;
- To choose the most efficient methods and machinery for each stand, taking into account the synergy between saw/pulp/energy wood;
- To fit the investments, or set objectives for R&D work.

Materials & methods

The methodology has been applied in two case studies for which the lack of chainsaw operators is becoming increasingly problematic:

1. Hardwoods in the West-Centre part of France, where the mechanization is already quite present in coppices, but not enough for the wood supply of local mills;
2. Young, regular stands in public forests from the mid-North of France, where first thinning are critically postponed.

The crucial point in this methodology is the elaboration of a typology of hardwood stands, reflecting the specific difficulties of mechanization:

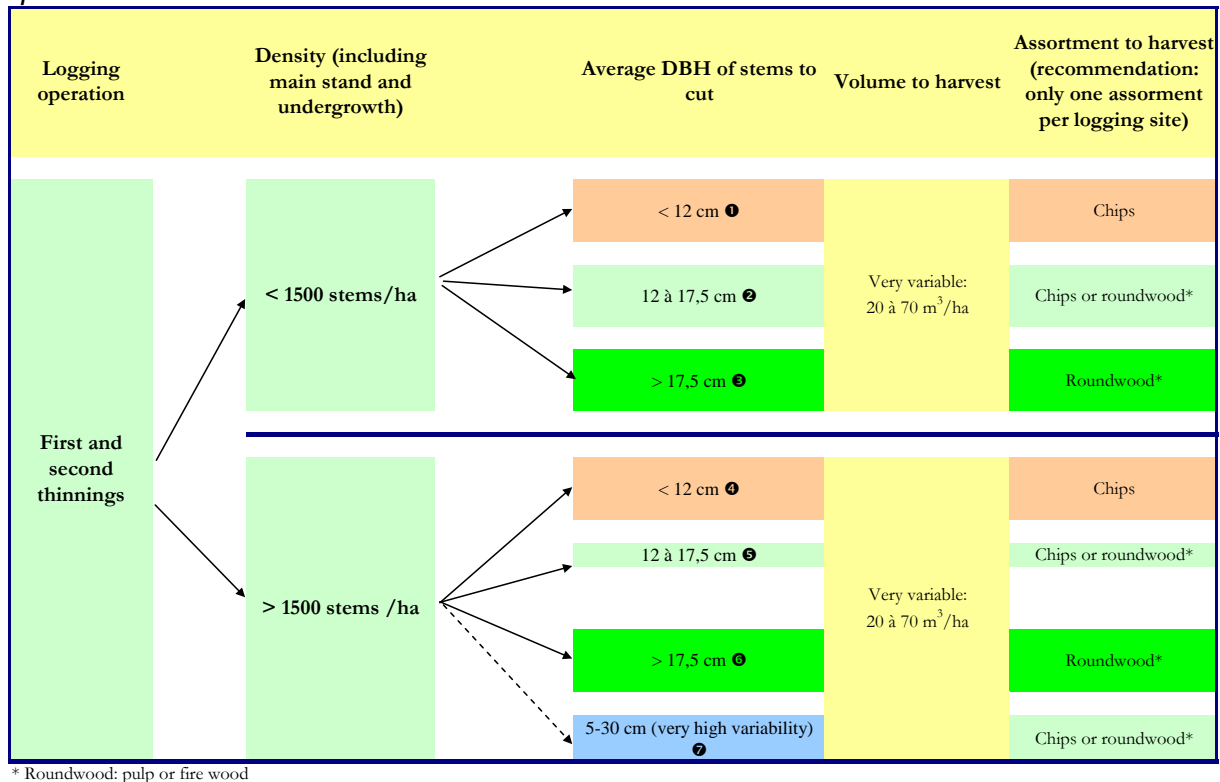
- (i) Precise definition of the mechanization constraints (stumps, crooked trees, branchiness, etc.);
- (ii) Translation of these constraints in stand descriptive parameters commonly used by the National Forest Inventory (case study number 1) or the National Forest managers (case study number 2), such as the density per hectare, the Diameter at Brest Height, etc;
- (iii) Analysis of the data from the National Forest Inventory and the National Forest managers and definition of a stand typology,
- (iv) Determination of the mechanized harvesting systems best suited to each type.

Results

In case study number one, the challenge was to classify 7,700 National Forest Inventory's plots, concerning very variable hardwood stands, in order to find a simple typology. We chose 5 criteria representing the difficulties to mechanize the harvest: the species, the main type of stand (high forest, coppices, mix of the two), the DBH, the variability of diameters and the global tree form factor defined by taking into account the dominant height, the branchiness and the straightness. By crossing those criteria, we determined 26 kinds of hardwood stands for which we knew their geographical and standing volume distributions.

In case study number two, stands are less variable than in the previous case study but present two main difficulties for mechanization: a very high density (up to 4.000 trees per hectare, with both merchantable and non-merchantable stems) and a small average volume per tree (below 0.3 m³/tree). The stand typology was based on these two criteria, completed by the average distance between the skid trails and the soil sensitivity to compaction by heavyweight machineries (Pischedda and al., 2009).

Figure 1. Stand typology for young regular stands and first recommendations for the logging operations.



In these two case studies, for each type of stand, we looked for adapted mechanized solutions. They could be harvesting techniques known in France, well-adapted and for which we have already had productivity data (Cacot, 2009), or techniques that seemed interesting but for which we did not have references yet (harvesting systems used abroad but not developed in France or not in the concerned stands) and would still need to be tested. The main proposed systems were:

- CTL softwood head: usual Cut-To-Length system developed for softwood;
- CTL "hardwood" head: heavy duty softwood head with modifications made by manufacturers (number of knives, number and size of rolls, top saw...) to adapt it to hardwoods (ex: AFM60 HW);
- Specific hardwood head: heavy duty CTL head specifically built for hardwood (ex: Charlier CA562HW, Risley Rolly II);
- Separation of the felling and the processing;
- Harwarder with head for energy wood.

At this time, we have quantified for each system the standing volume per region and the volume that could be potentially harvested for the 5 or 10 next years.

Table 1. Distribution of the potential harvest for the 10 next years (x 1.000 m³) according to the proposed logging system, for Centre-West France hardwood stands.

	Harvesting systems						Non merchandisable
	Usual CTL softwood head	Small CTL softwood head	CTL "hardwood" head	Small CTL "hardwood" head	Specific hardwood head	Felling head + processing head	
Potential volume for harvest for the 10 next years (x 1.000 m ³)	2.107	5.570	14.338	28.157	24.716	23.455	20.348

Discussion and conclusion

This data is important for both wood-supplying companies and the National Forest managers to plan their investments. But Table 1 highlights the need of further R&D works. Indeed, existing "hardwood" heads are proving not to be satisfactory (too fragile and low efficiency). Additionally, the specific hardwood heads needed are too large and too heavy for the French forestry context. Finally, for many stands, no current systems or techniques are suitable. Development work between researchers and forest machine manufacturers have now started for obtaining new processing heads that better adapted to hardwoods (Cacot and al., 2007).

Keywords: Mechanization, Hardwood, stand typology, harvesting systems

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A forwarder trail generator using GRASP

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Abstract

The planning of ground based harvesting operations is a task that receives little attention in practice. On occasion, the access trails are manually planned by a forester, but the location of forest machine trails are usually decided by the machine operator. There are two possible reasons for this; firstly, forestry planning is traditionally a labor intensive process requiring field work to ensure good plans and secondly, forest machine operators are quite good at working efficiently.

Today, airborne laser scanning is available at reasonable cost, and we hope that the resulting digital elevation model can be utilized for detailed planning of harvesting operations. Optimization of terrain transportation using a computer cannot only increase the net profit, but also can easily incorporate other objectives, such as social or environmental values.

In this work, we wish to optimize the layout of terrain transportation trails and estimate the cost of terrain transportation. To do this, we introduce a model where the machine can reach timber from the trail. Using the crane, the machine can pick up logs that are some distance away. When considering a continuous model of the terrain, there are an infinite number of solutions that will cover the area. When making a computerized model, we use a discrete subset (i.e. vertices), which renders an exponential number of possible solutions.

The problem is to find a set of vertices (i.e. trails) from which harvesters and forwarders can reach the economically viable timber at minimum cost, and connect those vertices to existing roads. This is similar to the Steiner Minimal Tree Problem (SMTP), a known NP-hard problem (Promel and Steger, 2002).

When trying to solve NP-hard optimization problems, exact methods may run out of computing resources. For this reason, metaheuristics are often used. In this work, we are using the thoroughly tested metaheuristic Greedy Randomized Adaptive Search Procedure (GRASP) (Feo and Resende, 1995).

We are using estimated net profit as an objective function, given by $f = V(P - (C_h + C_{ff} + C_f))$ where V is the timber volume at the vertice, P is the average price of timber, C_h is the cost of felling, bucking and delimbing, C_{ff} is a fixed cost of forwarding and C_f is the variable cost of forwarding that is dependent of the driving distance.

The variable cost of forwarding, C_{fB} , at a vertice, B , is $C_{fB} = C_{fA} + C_{fAB}$, where C_{fA} is the cost at the next vertice on the trail towards a forest road and C_{fAB} is the cost of transportation from B to A , given by $C_{fAB} = C_d d r p$, where C_d is the cost of transportation per m^3 per m traveled in flat terrain, d is the distance, r is a factor regarding roll, given by equation (1), and p is a factor regarding pitch, given by equation (2).

$$r = 1 + \frac{10\Delta e_r}{d_r}^4 \quad (1)$$

$$p = 1 + \frac{2\Delta e_p}{d_p}^4 \quad (2)$$

Δe_p is the difference in elevation at two grid points in the traveling direction and d_p is the distance between the two points. Likewise, Δe_r is the difference in elevation at two grid points perpendicular to the traveling direction and d_r is the distance between the two points.

The GRASP metaheuristic is based on a constructive, greedy heuristic that iteratively adds a short trail segment to existing trails and roads. Starting with an existing forest road, we calculate the increase in profit from several short trail segments, typically of length somewhat longer than the crane reach. When using the greedy heuristic, we add the trail segment with the largest increase in profit. This process is repeated until the map is covered.

When using the GRASP metaheuristic, we randomly select one of the $p\%$ best trail segments, where p is the GRASP percentage. When the map is covered, we save the solution and repeat the whole process for a number of runs. Typically, most of the saved solutions will be worse than the greedy solution, but some will be better, and the best solution will be chosen for implementation.

The method was tested using two test cases, one with a semi-random terrain and one smoother terrain with a peak. The GRASP metaheuristic improved the solution by 5.6% and 2.3%, respectively, compared with the greedy solver.

Keywords: forwarding, GRASP, harvesting, metaheuristic, transportation

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***Acacia mearnsii* debarking: comparing different debarking technologies in the KwaZulu-Natal and Mpumalanga forestry regions of South Africa.**

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Acacia mearnsii seeds were first introduced into South Africa from Australia in 1864 (Sherry, 1971). About ten years later the first plantings were carried out primarily for firewood, shelterbelts and shade for livestock. The use of the bark extracts for tannin products was only discovered in 1888 (Dunlop and MacLennan, 2002). *Acacia mearnsii* plantations make up approximately 7.6% of the South African plantation forestry estate, amounting to a total of 95 572 hectares (Forestry South Africa, 2008). In 2008, *Acacia mearnsii* accounted for a total roundwood production of 924 600 m³, 4.6 % of the total annual roundwood production in South Africa (Forestry South Africa, 2008). *Acacia mearnsii* extract is mainly used as a vegetable extract in the tanning application of leather for production of products such as shoes, belts, bags and saddles. *Acacia mearnsii* extract is also used for the production of industrial adhesives used in the manufacturing of weather proof and boil proof particle board, plywood, fiber board and corrugated cardboard (Dunlop and MacLennan, 2002).

In South Africa, most debarking of *Acacia mearnsii* is carried out manually. Finding labor to carry out cost effective debarking is becoming increasingly difficult. Further to this, *Acacia mearnsii* trees are usually small with bark that is difficult to remove. Often no debarking takes place during the drier winter months, due to the wood-bark bond being too strong (South African Forestry Handbook, 2000). If the bark is to be used by a processing facility, then bark quality in terms of dimensions, amount of damage to the bark and time after debarking also becomes important. One of the most limiting factors to mechanized *Acacia mearnsii* debarking, is the quality of the bark that is produced. If a large area of the cambium layer is exposed during the debarking process, caused by the knives or rollers damaging the bark, it increases oxidation leading to a darker tannin powder. The mechanical debarkers also produce bark of varying length and size. Consistency of bark size once chipped, is of vital importance for the processing plants. It determines the quality of the end product, due to it affecting the defusing process, by affecting the amount of possible extractives to leach out (Mimosa, 2007).

The processing plants are able to overcome incorrect chip sizes by using drum chippers to create acceptable sizes from larger chips of bark (Dobson, 2009). *Acacia mearnsii* bark processing brings with it a unique set of circumstances, because unlike *Pinus* and *Eucalyptus* species, the bark is not a waste product to be disposed of. *Acacia mearnsii* bark is processed to yield tanning extract (Dunlop and MacLennan, 2002; South African Forestry Handbook, 2000). In order to extract the tannin efficiently the bark needs to be resized, traditionally into uniformly small bark chips of 6 mm x 6 mm in dimension before it can be used in the leaching process. Increasing chip size reduces the extraction efficiency which in turn affects the profitability of the factory.

Mechanical debarking is fast becoming a reality in the South African forestry industry and there are factors influencing the change from manual to mechanical debarking. Internationally, mechanized debarking has taken preference over manual debarking due to labor being more expensive than in South Africa, and the operation being safer (Dunlop and MacLennan, 2002). In the past in South Africa, manual labor has been available and willing to carry out the task of debarking, but various factors are forcing the South African Forest Industry to start exploring the route of mechanical debarking, to form part of a semi-mechanized operation. Labor shortages, HIV/AIDS and forestry not being a first choice

career due to debarking being very difficult work, is causing productivity losses (Steenkamp, 2007; Grobbelaar and Manyuchi, 2000). During December and April, the labor is on leave. These dates fall during the peak debarking season, therefore three productive weeks are lost per year. With debarking being one of the most prominent areas for the occurrence of injuries, safety will also be improved through mechanization or partial mechanization of harvesting systems. Due to the abovementioned factors, Forest Engineering Southern Africa (FESA) has taken decisions to identify various systems and machines that could be used to produce a product more cost effectively, with a greater productivity and at the same quality as the currently used manual systems.

When using mechanized debarking, there is buffer stock between the felling and processing operations, therefore ensuring a safer operation. The factor of year round harvesting could also be improved, therefore preventing the need for large stocks of timber. As people would be constantly working near these timber stocks, timber theft may be reduced. The machines that have been included in this research are machines that have the potential to be used in the debarking process. These machines also have the potential to produce bark of the correct dimensions and quality. The dimensions and shape of the bark will have an effect on the processing facilities and the product produced. If the results obtained from the research shows positive figures towards mechanical debarking, the machines could be used internationally to debark similar *Acacia* species.

The research covered the effect of these bark dimensions/shapes on the extraction efficiency as well as the effect on the quality of the end product. This research will investigate the debarking of *Acacia mearnsii* using:

1. The Demuth mobile debarker (DDM 420), which is a ring debarker that loosens the bark from de-branched logs with rollers, cuts it to size with knives and removes it with scrapers. The bark is removed in chip form (Demuth machines, 2008).
2. The Hypro debarker, which is a tractor mounted processor that removes the bark from tree lengths by applying pressure with the feed rollers. The bark is removed in strips of varying length depending on the wood-bark bond strength (Hypro, 2008).
3. The Hyena MK 3 debarking head, which removes the bark from tree lengths by applying pressure with the feed rollers. The bark is removed in strips of varying length depending on the wood-bark bond strength. The Hyena was used only to debark the tree lengths, no processing took place.

The research site for the Demuth and the Hypro debarkers were conducted in the KwaZulu-Natal midlands, and for the Hyena debarker in Mpumalanga. The research trials for each of the debarking technologies were conducted during summer as well during winter, when traditionally, no debarking of *Acacia mearnsii* takes place. This was done to determine the effect of a stronger, wood-bark bond strength on the productivity of each of the technologies.

The effect that tree volume, strippability and tree form had on the effectiveness of the three debarking machines was determined. The machines were analyzed in terms productivity (m^3 per productive machine hour), cost per m^3 , quality of debarking and the quality of the bark produced for the processing facilities.

Tree volume was divided into five classes, ranging from 0.02m^3 to 0.35m^3 . The productivity of all three machines increased with an increasing tree volume.

Tree form was divided into three classes based on the physical form of the tree, ranging from trees that were straight to trees that had physical defects such as a fork, sweep or crook. The productivity of each of the three debarking technologies decreased when the trees were malformed or had a physical defect.

Strippability was based on the wood-bark bond strength, and was divided into five different classes. The effect of each of these classes on the productivity of each of the debarking technologies was determined. The productivity of each of the technologies decreased when there was a stronger, wood-bark bond strength.

Bark samples were collected on a daily basis from each of the three debarking technologies. Samples were taken under different tree volume, tree form and strippability classes. Manually debarked samples were also taken under the same conditions as each of the technologies, and from the same compartments. The samples were then analyzed at the laboratory of one of the processing facilities. The samples taken from each of the three debarking technologies showed that the quality was acceptable when compared to the manually debarked samples.

Field Evaluation of Four Biomass Harvesting Systems in the Southern United States

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Increased interest in renewable energy generation around the world has created demand for cost-effective sources of “green” energy. In the southern United States, forest biomass is the most readily available source of renewable energy. Existing forest harvesting systems efficiently harvest traditional forest products (roundwood products and pulp-quality chips). The desire to capture unutilized residual forest biomass has led to the development of a number of biomass harvesting systems. Empirical evidence on the potential production and costs of these new systems is not widely available. Since 2006, we have performed operational studies of four of the most common biomass harvesting systems in the southern US. This report combines the results of these studies to examine the cost and productivity differences.

We performed work sampling and gross time-studies on four biomass harvesting systems common in the southern US:

- Dedicated horizontal grinder systems processing roundwood harvest residue
- Dedicated horizontal grinder systems processing in-woods delimber-debarker-chipper residue
- Dedicated whole tree chipping systems producing fuel chips only
- Chippers processing roundwood harvest residue and understory stems integrated with a roundwood harvesting crew

We examined three different harvest crews for each system. Detailed system and site descriptions can be found in Aman *et al.* (2010) and Baker *et al.* (2010). We recorded system utilization, hourly productivity, and sources of delay for a minimum of three days on each crew. The Auburn Harvest Analyzer, a harvest cost analysis spreadsheet (Tufts *et al.* 1985), was modified to generate cost estimates per green tonne for each system, using the same base cost assumptions and reported machine costs. A thorough costing methodology for integrated chipping operations was detailed by Baker *et al.* (2010). Our results represent an average of costs observed across the studied operations. We calculated costs both using observed system characteristics and assuming a 50% utilization rate of the chipper/grinder. Recorded feedstock moisture and energy content were used to determine cost per gigajoule (GJ).

Table 1. Hourly production in green tonnes per scheduled machine hour and harvesting cost per green tonne (gt) and per gigajoule (GJ) of four biomass harvesting systems operating in the Southern US. GRW – Grinder processing roundwood residue, GCC – Grinder processing clean chipping residue, WTC – Whole-tree chipping system, CRW – Chipper processing roundwood residue concurrent with roundwood harvest.

System	Productivity (gt/SMH)			Harvest Cost (\$/gt)		Harvest Cost (\$/GJ)	
	N	Mean	Range	Observed Util.	50% Util.	Observed Util.	50% Util.
GRW	11	22.3 ^a	18.3 – 42.7	23.70	19.90	2.00	1.60
GCC	10	27.9 ^{a,b}	12.2 – 30.4	22.70	19.10	1.90	1.60

WTC	9	29.9 ^b	18.3 – 53.1	23.80	20.90	2.00	1.80
CRW	21	5.7 ^c	0.3 – 14.6	14.20	11.30	1.20	0.90

^{a,b,c} Different letters within a column indicate significantly different values ($p < 0.05$)

Average hourly production varied significantly between the integrated harvesting system using a small chipper for a portion of the time and dedicated systems using full-time chipping or grinding machines ($p < 0.001$) (Table 1). Grinders processing roundwood residue had significantly lower production than whole-tree chipping systems as well ($p < 0.05$) (Table 1). The main cause of low production in the integrated system was the time spent by the loader processing and loading roundwood products (Table 2). Grinding systems were utilized only 30-40% of the time due to a lack of available trucks to haul material. Whole-tree chippers maintained higher utilization due to a slightly better flow of trucks, but were still hampered by low utilization. Poor markets limited the ability of contractors to increase wood flow during the study period, but increased market quotas offers the potential for substantial production increases from the dedicated biomass harvesting systems.

Table 2. Machine utilization and sources of delay as a percentage of scheduled machine hours for chipping or grinding machines in four biomass harvesting systems operating in the Southern US. GRW – Grinder processing roundwood residue, GCC – Grinder processing clean chipping residue, WTC – Whole-tree chipping system, CRW – Chipper processing roundwood residue concurrent with roundwood harvest.

System	Chipping/Grinding	Handling Roundwood	Wait on Trucks	Mechanical Delays	Other Delays
GRW	39%	0%	50%	4%	7%
GCC	38%	0%	49%	9%	3%
WTC	44%	0%	31%	11%	14%
CRW	24%	55%	0%	4%	17%

System costs also varied between the integrated system and the three dedicated systems (Table 1). Integrated systems benefitted from a lower cost chipper and carried only the incremental cost increase associated with harvesting biomass rather than the full cost of the harvesting system. The dedicated systems were able to lower their costs by achieving higher utilization, but still were not able to match the costs of integrated operations. Integrated operations struggled to succeed when the chipper was operating at 50% utilization because of the need to produce roundwood as well, whereas dedicated operations should be working consistently above 50% utilization.

The costs of integrated systems suggest they offer a better alternative for biomass production, but their utility is limited to a fairly narrow range of site conditions due to the need to produce both roundwood and biomass chips (Baker *et al.* 2010). Higher production can be achieved with greater flexibility in site characteristics using dedicated systems, though the costs of producing feedstock increase. The potential to include field-drying of raw materials with dedicated systems also offers the opportunity to further decrease costs per GJ.

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The impact of forest operations research

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Abstract

Statistics indicate a positive correlation between investments in forest operations research (OR) and the development of productivity in the Swedish forestry sector. However, the impact of research investments is very difficult to quantify with general data. The only way to obtain reliable cost benefit estimates is to study the effect of individual research projects, where R&D results have been implemented and all costs associated are known.

Hence, Skogforsk has carried out a study where six OR projects have been analyzed from that perspective. The effects on revenue, productivity, operational costs, etc. were investigated and put in relation to the corresponding research investments after that the OR findings had been implemented. Thus, the total impact of the applied research results was calculated.

The results from the study show that OR can be very profitable. The returns on the investment and the pay-off time for the six different R&D projects were impressive. A key to success seems to be close dialog with the forestry sector when planning the R&D work, and thus identifying projects with high gain potentials.

A discussion of general interest is how the level of accepted risk in applied R&D projects affect the average return on investment and whether benefits from successful OR outweigh the costs for unsuccessful.

The asymmetric grapple – a multi-purpose tool

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During 2009 Skogforsk made a series of studies on an asymmetric grapple (Figure 1) manufactured by Hultdins AB in a variety of work tasks. The grapple was studied with the grapple mounted on forwarders forwarding traditional roundwood, partly de-limbed energy wood, and logging residues as well as mounted on cranes feeding chippers with residues piled on landing. The studies show that the asymmetric grapple (AG) increased forwarding performance by 1.4 % for roundwood, 0 % for energy logs compared to the performance with a log grapple (LG) and 9.1 % for residues compared to a residue grapple (RG). The changes in time consumption occurred when loading and unloading (Table 1). Compared to the standard grapples on the studied forwarders, no increase in the amount of soil contaminations of log and fuel assortments was recorded for the new grapple.



Figure 1. Three types of grapples were studied, from left a log grapple (LG), a residue grapple (RG) and finally an asymmetric grapple (AG).

A residue grapple was a more effective tool than the asymmetric grapple when feeding chippers. This was partly because it was easier to get a good grip of residues from the stack and partly because it was easier to pick up the last residues on the landing with a residue grapple. However, residues forwarded and piled with the A-grapple were significantly faster to chip because piled residues were more co-oriented and less entangled in each other within the pile than after piling with a residue grapple (cf. figure 2).



Figure 2. When loading logging residues the asymmetric grapple forces the residues to form a co-orientated structured bundle.

There was a large difference between chipper operators in how well they were able to adapt to the new grapple and thus how efficient their work was. An observation is that the operator has to expect a different grapple than the one he is used to will have other properties due to differences in grapple design and geometry. Therefore, training is important as well as the operator's willingness to adapt his way of work in order to maximize the advantages of a new piece of equipment.

Conclusions

Mounted on a forwarder, the asymmetric grapple is a versatile tool that was as good as or better than the standard grapples for all assortments forwarded.

A chipper preferably should be fed by a residue grapple equipped loader but the residues chipped should have been forwarded by a forwarder with an asymmetric grapple.

The potential to use the same forwarder for forwarding both roundwood and residues with an equal or increased performance unlocks substantial reductions of total harvesting costs. The effect is particularly strong for small logging areas, where machine relocation costs constitute a large part of the total harvesting costs.

Table 1. Results of the separate studies

Type of work	Comparison	Effect on time consumption
Forwarding of saw logs and pulpwood in a late thinning.	AG / LG	AG 1.3 % faster when loading (not significant), and 4.3 % faster when unloading.
Forwarding of partly delimbed energy wood (~slender pulpwood with some branches)	AG / LG	No observed differences between grapple types.
Forwarding of branches and tops (logging residues)	AG / RG	AG 11.4 % faster for loading and 17.2 % faster for unloading.
Feeding a chipper when chipping branches and tops	AG / RG	Chipping up to 50 % slower when an AG was used. Residues forwarded with an AG equipped forwarder were 20 % faster to chip than residues forwarded with a RG equipped forwarder.

Slash-bundler in clear felled Eucalyptus plantations of Australia.

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Abstract

There are many different biomass harvesting technologies which can be classified based on logistics, the source of the biomass, and the machinery used. Slash-bundlers have been used to collect forest harvesting residues for biomass utilization. In Australia, the harvesting residues are an estimated volume of 3 million cubic meters. This study aimed to evaluate the productivity and cost of bundling operation, assessment of collected and left slash in the operation site and the cost of site preparation in clear felled areas of *Eucalyptus nitens*. In a distinct plot, first the ranking of the slash into windrows by tracked excavators was timed. Then continuous time study methods were applied to evaluate the bundling production. The work cycle of bundling operation included loading the slash, bundling, cutting and removing the bundles. Any working delay was recorded during the operations. After bundling, the area where slash was left was measured per ha using a systematic-random grid. This paper presents the site preparation and bundling costs. This information can be useful for planning biomass utilization in the future.

Introduction

There are many different biomass harvesting technologies which can be classified based on logistics, the source of the biomass, and the machinery used. Slash-bundlers have been used to collect forest harvesting residues for biomass utilization. In Australia, the harvesting residues are an estimated volume of 3 million cubic meters (Ryan et al. 2001). Slash bundlers are one of the common biomass harvesting machines used to produce energy from harvest residues. The objectives of this paper are as follows: an evaluation of the productivity and cost of bundling operations, assessment of collected and left slash in the operation site and costs of site preparation in clear felled area.

The study area was located at Guide Road in Burnie (Northern Tasmania). The site was planted with *Eucalyptus nitens* in Oct. 1995 and clear-felled in March 2010. The yield estimation was about 236 tn/ha. The area was harvested using cut-to-length method. The machinery consisted of a feller-buncher, skidder and excavator for loading the logs on the trucks. Minimum harvestable log diameter was approximately 10 cm.

Study method

A continuous time study method was used to evaluate the production of a Pinox bundler (Figure 1) in a plot of 0.14 ha.



Figure 1. Pinox slash-bundler

Bundling operations included loading the slash on the bundler, bundling, cutting and then removing the bundles not to be left on the ground. Working delays were also recorded. It must be mentioned that the bundler was operating using manual method and automatic bundling was not used. The productivity is presented based on PMH0 (productive machine hours without any delay) and gross time (including delays).

The P200 Komatsu excavator was used to concentrate the slashes into rows before bundling. After bundling, the excavator set up the cultivation head to cultivate the plot. Raking and cultivation time in a plot of 1.05 ha was recorded to evaluate the site preparation cost (Figure 2 and 3).



Figure 2. Windrow making by excavator



Figure 3. Cultivation between the windrows

Collected slash by the bundler was estimated by multiplying the number of bundles from the area by average weight of bundles. After bundling and cultivation, a systematic-random grid was set up in the bundling site. Within the bundling site, 15 plots with the area of one square meter were established along 3 intersecting lines (Cuchet et al. 2004). All the remaining slash, and therefore biomass, within the one-square meter plots was collected and weighted using a scale.

Results

Table 1 presents the summary of production and fuel consumption of bundling.

Table 1. Average productivity and fuel consumption of bundling operation

Productivity (tn/PMH0)	Productivity (Bundles/PMH0)	Gross productivity (tn/h)	Cost (\$/tn)	Fuel consumption (l/bundle)	Fuel consumption (l/tn)
11.8	20.8	10.5	23.8	0.8	1.4

All delays were mechanical ones (12% of working time) in a pre-concentrated area. The delays were caused because of the failure in the stirring section of a bundler. Figure 4 illustrates the portion of each work elements to total work time. Loading the slash and bundling have the largest portion.

The productivity and cost of site preparation by excavator are included in Table 2. The hourly machine cost of \$120 has been taken into account for the excavator based on the work contract. Raking into windrow is more time-consuming, more expensive and more fuel-consuming.

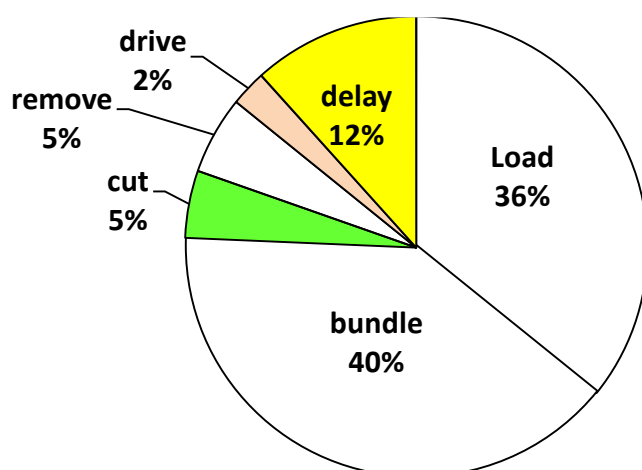


Figure 4. Bundling in concentrated

Table 2. Site preparation costs by excavator

Site	Area (ha)	Work type	Productive time (hr)	Total cost (\$)	Productivity (ha/h)	cost (\$/ha)	Fuel consumption (l/ha)
E	0.908	Raking into with windrow excavator	2.790	334.8	0.325	368.8	71.60
C	1.05	Raking into with windrow excavator	3.071	368.52	0.342	350.1	70.6
C	1.05	Cultivation	2.625	315	0.4	300	59.8
-	-	Remove raking head	0.463	55.6		-	-
-	-	Attach cultivation head	0.377	45.2		-	-

Table 3 includes the statistics of collected slash, left-slash and bundle size. Using two disks samples from bundles, the contaminant percentage within the bundle was measured. Based on this test, 8.9% of the bundle weight was contaminant. Total slash averaged at 209.13 tn/ha. The slash-bundler collected 66.3% of the slash in the clear-felled study area.

Table 3. Harvesting residues assessments in the bundling area

Site	Bundling site
Area of site (ha)	0.1397
Number of bundles per area	34
Average volume of bundle (m ³)	1.55
Average length (m)	2.97
Average weight of bundles (tn)	0.57
Total weight of the bundles per area (tn)	19.38
Collected bundles (tn/ha)	138.7
Left-slash (tn/ha)	70.4
Collected slash (%)	66.3
Left-slash (%)	33.7
Total slash (tn/ha)	209.1

Conclusions:

The slash amount of 209.13 tn/ha indicates that there is considerable volume of harvesting residues at the clear-felled plantations which can be used as a biomass resource. Although one of the disadvantages of using a bundling system is the removal of nutrients from the stand, however, this study found that the left-slash averaged at 70.4 tn/ha. Thus further studies are required to investigate the impact of biomass removal on growth and sustainability of future rotations. Since slash-bundlers are an expensive biomass harvest machine, future studies may evaluate bundling in large whole tree operations where the trees are processed at the landing.

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The torque required to twist tree stumps - preliminary results

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Introduction and Objectives

As renewable energy replaces fossil fuels, tree stumps will become an important energy source in the future. In order to develop machines for harvesting stumps that are both efficient and environmentally friendly, it is important to understand stump properties and the ground disturbance associated with uprooting stumps. Previous studies have been published concerning the force required to lift stumps vertically (Lindroos *et al.*, 2010; Horváth-Szováti & Czupy, 2005; Czereyski *et al.*, 1965) and to drag them horizontally (e.g. Peltola *et al.*, 2000; Liley, 1985; Golob *et al.*, 1976). However, there is no information on the torque required for uprooting stumps by twisting. Anderson *et al.* (1989) investigated shear strength in different soils by twisting trees, and it is possible to estimate the torque requirements from their data, in figure 2, values for brown earths are shown. However, more exact information is needed in order to develop machinery.

Ground disturbance and the harvestable proportion of the stump are determined by how roots break or are loosened. The extraction methods used currently produce significant ground disturbance. This disturbance should be reduced if stumps are harvested by twisting. Therefore, knowing the required torque should lead to more efficient harvesting methods. In the future, stump harvesting could be integrated with roundwood harvesting as stumps are an extension of the butt log.

The objectives of this work were to quantify the effects of stump size, species and soil-type on the torque required to twist stump, and to measure ground disturbance. This paper presents preliminary results from the initial field trials.

Material and Methods

Stumps of pine (*Pinus sylvestris*) in a sandy sedimentary soil at a site near Vindeln in north Sweden were twisted in experiments conducted in August and October 2010. Before the experiment, tree height, DBH, crown diameter, bark thickness, live and dead crown base, and distance, direction and size of adjacent trees (within 3 m of the stump) were measured. The trees were cut at a height of 1 m - 1.5 m and holes were dug under the four major roots. The depths of the holes were measured and the boundary of the mineral soil was marked at the stump. The torque was measured while each of the seven stumps was twisted, after which, soil samples were taken and the soil temperature measured.

A Volvo L50 tractor was used to lift the stump, twisting rig into place around the stump, and to power the winch. The rig was placed vertically around the stump and four 1.5 m chains were fastened around each of the four major roots and reconnected to the rig. Because the rig's circular design, pulling forces were developed on all sides of the stump at a constant angle (Figure 1). The winch cable from the tractor was fastened to the apex of a triangular bar. Two further cables were then attached to each of the other two corners of the triangle; one connecting directly with the rig and pulling in the direction of the tractor, the other connected after having passed through a pulley anchored to a tree, reversing the direction of the pulling force. The force (F) was measured in a load cell placed between the pulley and the anchor tree.

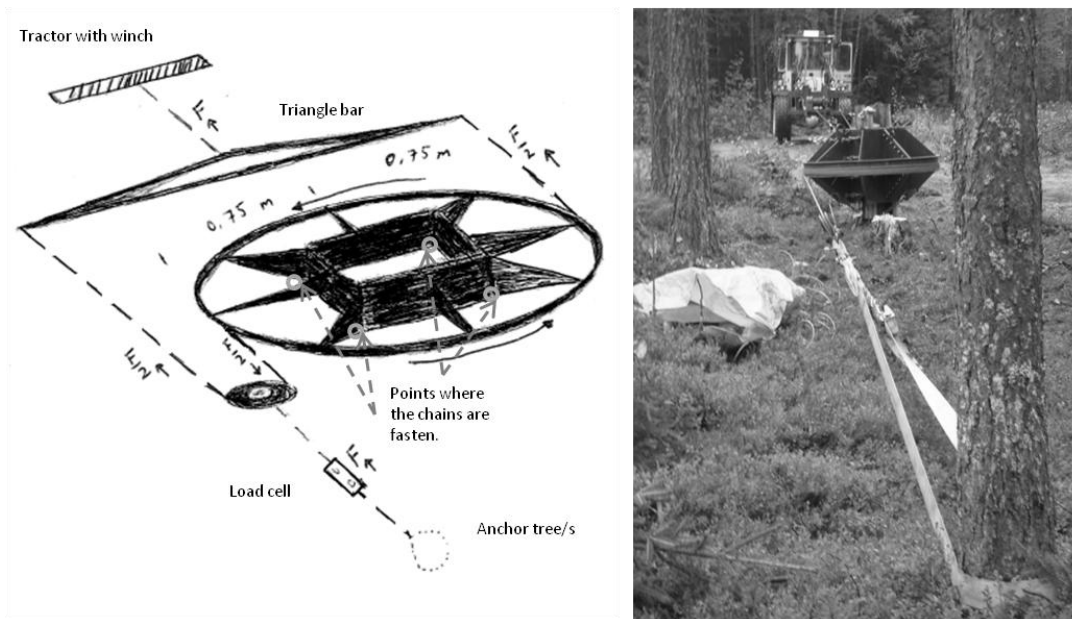


Figure 1. Experimental set up and distribution of forces in the equipment.

The torque (T) was calculated from the following equation:

$$T = \frac{F}{2} * 0.75 + \frac{F}{2} * 0.75 = F * 0.75 \quad (1)$$

Results

The preliminary results indicate that torque increased linearly as DBH increases (Figure 2). Data is not included from one stump trial which was interrupted for safety reasons. Stump twisting produced one of three outcomes: a) the stump twisted completely; b) a small twist broke some roots resulting in a leaning stump; or c) all roots broke and the stump was left standing.

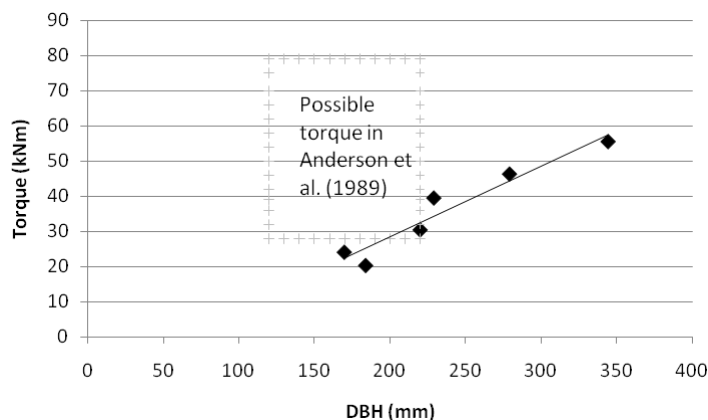


Figure 2. The relationship between torque and DBH.

Discussion and Conclusions

Although all the twisting sequences had the best outcome, it is likely that the maximum torque was achieved. The major roots, around which the chains were fastened, had loosened so much that some or all of them had broken. Therefore, it is likely that the subsequent torque needed to uproot the rest of the roots would be significantly less. The torque required to uproot stumps is larger than any rotator can generate. The largest Rototilt from manufacturer Indexator (Vindeln, Sweden) has a maximum torque of 8.4 kNm (Indexator AB 2010).

Our torque values were lower than those predicted by the data of Anderson *et al.* (1989). This may be due to assumptions made concerning the parameters for estimating the torque and that the soil was lighter in the present study.

In practice, it is clear that stumps cannot be harvested using torque alone. We suggest that roots could be cut or torque should be combined with other forces acting horizontally and/or vertically; these combinations are under further investigation. Another possibility we will test with a harvester or excavator, similar to Morgan (1973), is to use a wrench-like technique to twist the stump 90-120°.

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Developing the cut-to-length technology and method: Innovation through cooperative development

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World class forest machines are an absolute prerequisite for profitable forestry, and hence a basis for the Swedish forest industry sector. The world market for wheel-based cut-to-length (CTL) machines amounts to circa 1 billion euro. Sweden and Finland account for 30% of the market. The most important growth markets are South America, South-east Asia and China, with increasing plantation forestry, and Russia. Forest machine manufacturers are often relatively small in terms of turnover, but strong in terms of technical competence and innovativeness. Their ability to grow stronger and develop, for example, with the support from advanced technological R&D at universities, is a strategically important issue to ensure continuous productivity development.

Cooperative development of the CTL technology and method was a key to success during the mechanization era, circa 1960-1990. The innovation system comprised users, manufacturers and researchers. Over the past 20 years, important developmental resources have disappeared or changed at forest companies and at research organizations due to fierce cost pressure in the business. The machines are now owned by small contractors rather than forest enterprises resulting in contractors that often lack incentives and power for driving the technological development further. The development has implied that the purchasing competence has been weakened. The once so successful product development taking place in a strong customer-supplier relationship is being threatened. The productivity increase accomplished during the mechanization era by forest enterprises and machine manufacturers together with researchers now has to proceed under entirely new conditions.

This presentation provides examples of current cooperative efforts in the innovation system. The first example is TSG (<http://www.skogforsk.se/sv/Om-oss/Samverkan/TSG/>), a user cooperation group comprising representatives from machine-owning forest companies and contractors. By speaking with one clear voice to manufacturers and authorities when communicating the demands from the users, there is strong evidence of developmental success in concrete issues related to forest machine productivity, reliability and safety. The impression is that this mode of work is appreciated by the OEMs. TSG working groups include hydraulics, work environment and safety, operational follow-up, vehicle-ground interaction and fuel consumption. TSG has played a highly significant role in the improvement of, for example, hydraulic performance and fuel efficiency in practice.

The threshold for new innovations to reach serial production is high. The manufacturers are reluctant to produce prototypes, because the contractors are not eager to buy and use prototypes. Successful innovation and implementation rely on anchoring among strong users such as forest companies who benefit from productivity increases due to improved technology. Furthermore, there has to be participation from OEMs and (often) their sub-suppliers to secure the smoothest possible track to the production line. Finally, researchers have an obvious role in identifying new possible paths and in verifying the improvements of the innovation. Examples of successful and less successful innovation projects will be provided and discussed in this context.

Ongoing work in Sweden aims at creating an enforced forest technology cluster. All parts of the innovation systems will be addressed and held together by an organization constituted by the different actors in the system – OEMs and their sub-suppliers, machine buyers and their customers, researchers and the public. Needs in the sector and innovation possible to

implement within 3-10 years are in focus. The R&D part will involve a stronger participation from technical universities (for example, KTH, the Royal Institute of Technology) than has been the case earlier. As concerns the innovation process, an infra-structure for efficient innovation will be created in order to connect entrepreneurs with early customers and capital and to catch and refine ideas at an early stage together with machine manufacturers. Increased international cooperation, for example in the EU's research program, will be a prerequisite in this project. Benefits for the public sector include secured or improved employment in areas outside the city regions and sustained competitiveness in two export sectors, namely the forest industry and the forest machine industry. The goals imply world-leading innovative forest machine technology as regards R&D, manufacturing and practice, as well as forestry being a sustainable basis for growth and competitiveness for the forest industry. The market for CTL machinery is assumed to increase with 100% due to increased harvesting volumes in the world, increased mechanization and increased market share as compared to the tree-length method. In conclusion, the planned multi-million euro project will increase the competitiveness of the manufacturing industry and forestry's access to the best technology available.

The relationship between number of assortments forwarded in a load and time consumption

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Introduction

Forwarding loads can contain one or several assortments. According to a study by Kuitto et al. (1994), 14% of loads contain a single assortment, 44% contain two assortments and 26% contain three assortments. Edin & Forsman (2002) apportioned time consumption in forwarding operations as follows: loading 49.8%, unloading 22.7%, driving while loading 9.8%, driving empty 8.9% and driving loaded 8.7%. According to Brunberg (2004), if the number of assortments in a given harvesting operation increases from one to three, the time consumption increases by 0.21 effective (E0) minutes/solid m³ under bark (m³SUB).

Objectives:

To study how the number of assortments in harvesting operations influence forwarder productivity and to find the optimum number of assortments per forwarder load with respect to time consumption.

Materials & methods

A field study was carried out using a standardized circular test path (*figure 1*). The test path represented a strip road section in a hypothetical harvesting area, in which the total number of assortments was always five, but the log concentration on the strip road varied between 6.53 and 32.6 solid m³ on bark (m³SOB) per 100 m of strip road. The concentration of forwarded logs varied between 1.31 and 19.6 m³SOB per 100 m of strip road, depending on the number of assortments in a load (*Table 1*).

Table 1. Forwarded log concentrations according to log concentration on the strip road and the number of assortments in a load.

Log concentration on the strip road*	Number of assortments in the load	Forwarded log concentration*
6.53	1	1.31
6.53	3	3.93
19.6	1	3.93
32.6	1	6.53
32.6	3	19.6

*Unit: solid m³ on bark per 100 m of strip road

The time taken to forward the five different combinations of log concentrations and the numbers of assortments in a load were recorded. The work components were as follows: loading (L), driving while loading (DWL), unloading (Unl) and driving while unloading (DWUnl). One full load consisted of 30 piles. Pile size was standardized and each pile consisted of four logs. Random samples were collected during the study to determine pile size. The average pile size was ca. 0.27 m³SOB with a standard deviation 0.02 m³SOB. The load size, determined mathematically, was ca. 8.2 m³SOB. No distinguishable variation between the loads was observed during the study.

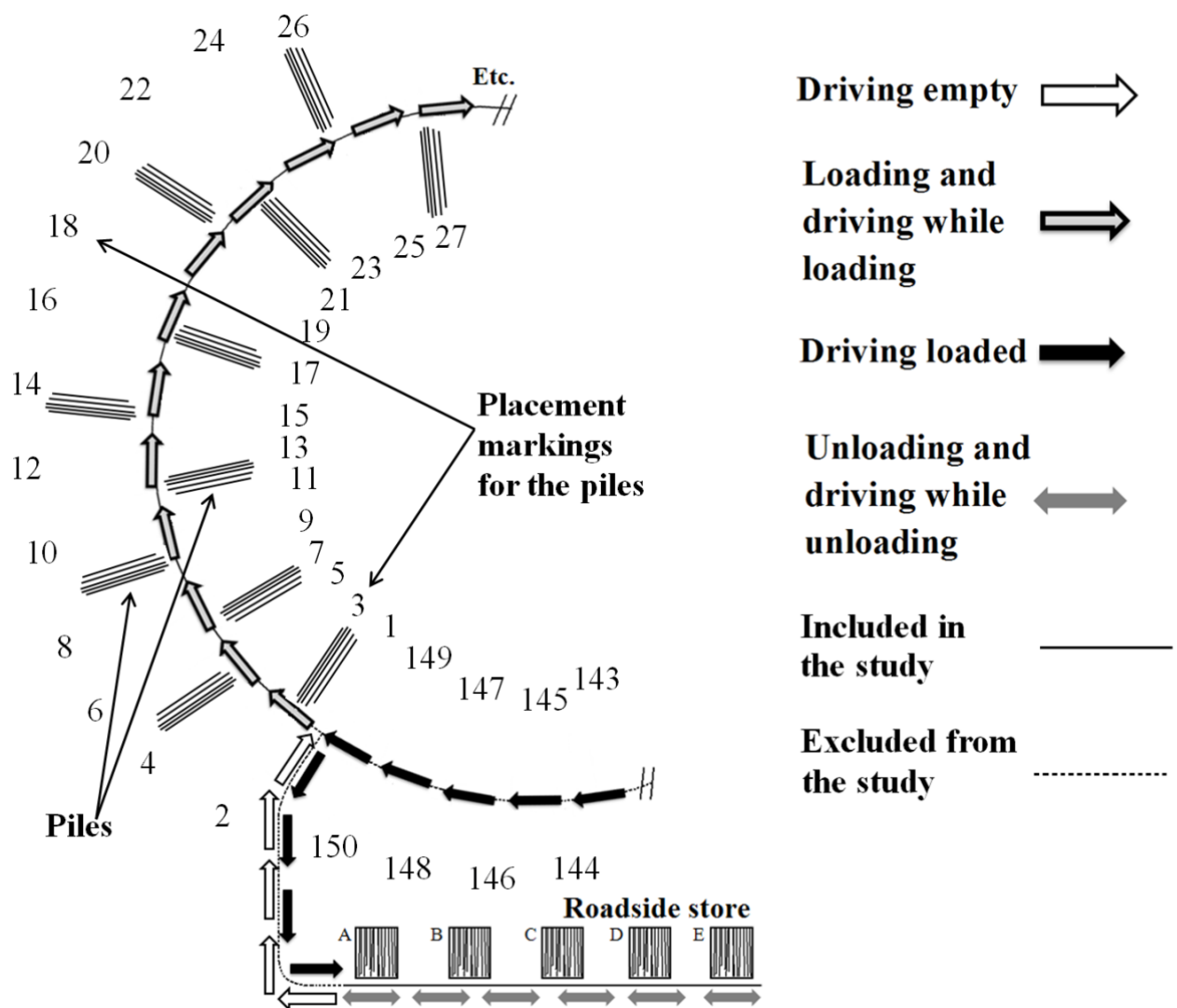


Figure 1. Standardized circular test path described by a hypothetical log distribution. Each pile included only one of five assortments. During the study the shortest run was 1/3 of the circuit (or 41.7 m) and the longest 5 circuits (or 625 m).

Results

At a high log concentration, forwarding time is minimized when there is only one assortment in a load; at a low log concentration it is quicker, overall, to forward more assortments at one time (figure 2). Thus, the optimal number of assortments in a load is inversely proportional to the log concentration on the strip road.

If the work components 'driving empty' and 'driving loaded' are ignored, increasing the number of assortments in a harvesting operation from one to three decreases the forwarder's productivity by one third.

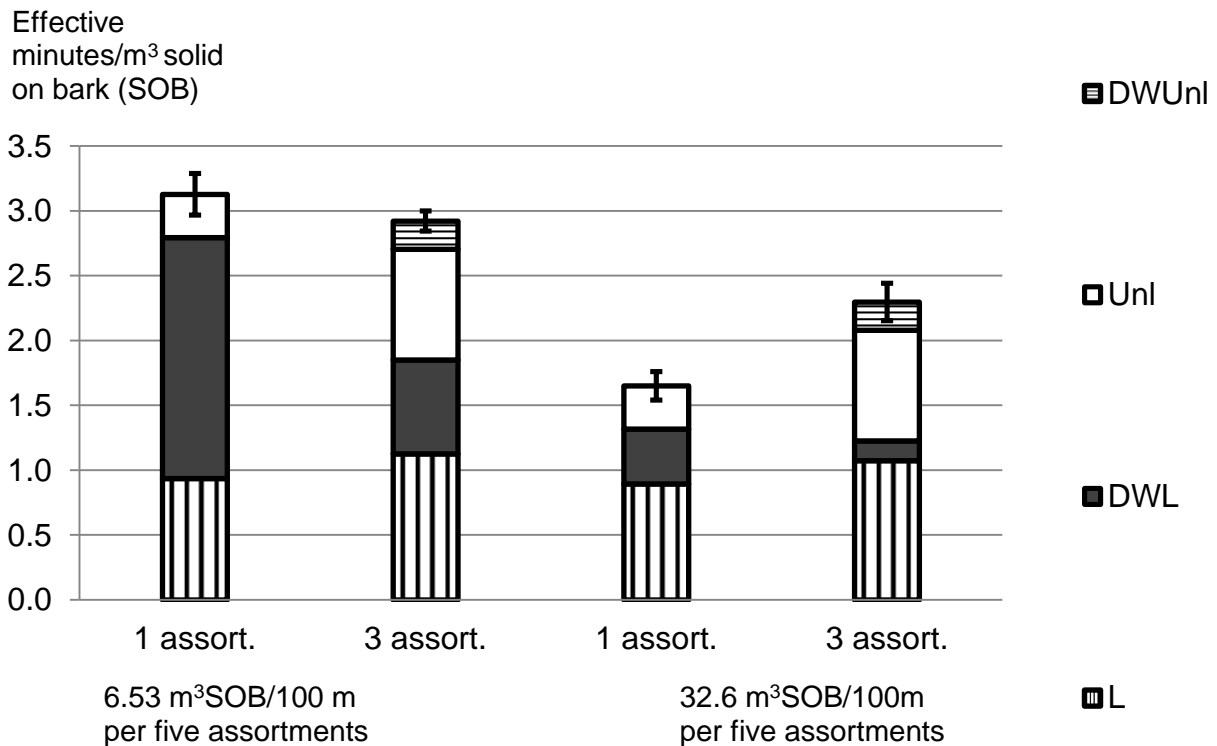


Figure 2. Time taken for the work components loading (L), driving while loading (DWL), unloading (Unl) and driving while unloading (DWUnl) for two different numbers of assortments in a load at two different log concentrations.

Discussion

According to the forest company Holmen's performance norms, an increase in the number of assortments in a given harvesting operation from one to three increases time consumption by 0.25 minutes per m³SOB when pauses of less than 15 minutes are included. (MoDo Skog 1993) Holmen's performance norms are quite similar to those given by Brunberg (2004). According to the current study, the corresponding value is roughly one effective minute (E0) per m³SOB, so the difference between performance norms and our data is significant. This suggests that productivity norms need to be amended.

Keywords: number of assortment, forwarding, loading, unloading

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Session 4

Value-chain optimization – from forest to industry/customer

Chaired by: Reino Pulkki, Bo Dahlin, Lennart Rådström & Matti Sirén

Issues and solutions for implementing operational decision support system – An application in truck routing and scheduling system

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Introduction

At the 3rd FEC, Skogforsk and FPInnovations, in partnership with the FORAC Research Consortium, presented their respective decision support systems (DSS) for timber truck routing, RuttOpt (Lidén et al., 2007; Anderson et al., 2008) and VTM (Audy et al., 2007; Marier et al., 2007). Various case studies using these DSSs, mainly with historical transportation data, had been conducted and significant potential benefits were reported (e.g. 5-15% reduction of total transport cost). These potential benefits come from improved routes obtained from cooperation opportunities among the truckers/shippers (e.g. backhaul) and better planning with Operational Research techniques. The case studies also demonstrated the technological feasibility of such systems (e.g. optimization routing model, GIS, web-based system, standardized data exchange). However, the adoption of these DSSs by the forest industry has not been successful up to now, i.e. the potential benefits found in the case studies have not been achieved for many Canadian and Swedish companies.

Issues related to adoption of timber truck routing DSSs

We discuss issues relevant to the adoption of these DSSs by the forest industry. Similar issues were found in both of the authors' countries. These DSSs include three basic components used in a sequential planning routine. A first component grasps transportation data from various sources. A second component performs the routes planning and then, a third component illustrates and evaluates the solution of the planning, i.e. a routing plan composed of improved routes. These DDSs are thus firstly intended to be used in a centralized-cooperative planning approach in which the DSS provides, in advance, improved routes for a given time horizon (i.e. one to several days). These improved routes should then be allocated to truckers for their execution. However, in the operational implementation of these DSSs, different issues can occur (see first and second columns in Table 1).

Potential solutions to foster adoption of timber truck routing DSSs

Potential solutions have been identified to foster adoption of timber truck routing DSSs (see third column in Table 1). These solutions involve entrepreneur-based logging and transportation companies (truckers' perspective) and forest companies (shippers' perspective). The first solutions listed have to do with improving the quality of the routing plan regarding its effective execution (i.e. issues 1-3) and speed up the information flows required to update (e.g. after the closure of a mill yard) the routing plan during its execution (i.e. issues 4-5). The solutions to foster cooperation among partners along the wood supply chain (i.e. issues 6-8) are the most challenging ones: they don't rely only on technology development but involve changes within the business relations between organizations that may be competitors on the market.

Table 1. Implementation issues with examples of impact and potential solutions

Issue	Example of impact	Potential solutions
1- Planning based on inaccurate information	Wrong estimation of volume at roadside or of travelling time/distance leads to trucks and loaders not fully utilized and mill demand not satisfied	<ul style="list-style-type: none"> - Use a security parameter to reduce, in the planning, the volume available at roadside except if the volume has been identified as the last volume to delivery - Update volume information during transportation - Use a validation tool to follow up travelling time/distance to reflect the 'real' route taken by the trucker from one site to another, see Flisberg et al. (2010)
2- Myopic planning over several planning time horizons	At each planning time horizon, routing model prefers the delivery of short transportation distance volume, thus creaming of the short transportation distance volumes, delaying and over-aging of volumes with long transportation distance and future peak (or shortage) in trucking capacity	Adapt the routing model to ensure that the delivery of the volumes with short and long transportation distance are balanced among the planning time horizons
3- Deterministic planning without considering the stochastic nature of wood transportation	Reduction of trucks' queuing time in the routing plan but trucks not planned by the DSS cause long queuing time in the execution of the routing plan	Integration of site-specific queuing functions in the planning that are regularly updated according to the automatic measurement of the queuing time of the site with transponders in some trucks
4- Routing plan update and synchronization with users in the execution of the routing plan	Delay and uncertainty in the information flows with truckers leads to truckers not informed on time to update their routing plan after e.g. closure of a mill yard	Develop a real-time rescheduling system working in tandem with the DSS
5- Software integration within the users' organisation	No implemented link between the DSS and the accounting system, thus manual typing of information between both	Develop an outsourcing service adapted to the forest industry
6- Benefits sharing between users	Unwillingness to cooperate if some users are not fully satisfied about the benefits sharing, thus unable to capture potential benefits proposed by the DSS	Select/adapt existing sharing mechanisms (see e.g. Audy et al., 2010) or develop a new one. A sharing based on a total cost (as in e.g. Frisk et al., 2010) seems more suitable with shippers while a sharing on each individual route appears more suitable with truckers.

Table 1. Implementation issues with examples of impact and potential solutions (continued)

Issue	Ex. of impact	Potential solutions
7- Fair routes allocation among truckers	Difficulty in recruiting truckers for less profitable or complex routes	<ul style="list-style-type: none"> - Allocation of a less profitable or complex route in a package of more profitable improved routes or with a bonus for the trucker - Develop tools to exchange and/or to bid on improved routes
8- Resistance to change by the forest industry	Opportunistic or competitive behavior by some truckers, thus unable to capture potential benefits proposed by the DSS	<ul style="list-style-type: none"> - Identify new business models suitable on a regional basis in order to increase cooperation, e.g. maintain the daily routing by each trucker but create support for cooperation between the truckers with map showing all the delivery flows realized the previous day(s) with relevant information. There is high probability that a load remains at the landing of each delivery flow. A trucker interested in a load will contact the trucker who is responsible for the landing and have a discussion to make an agreement on exchanging loads. - Develop tools to monitor routes done by truckers (transparency), e.g. use the DSS as a management tool for intensive (e.g. once a week) follow-up analysis of the work done by the truckers in order to give feedback to the trucker on the missing routing cooperation opportunities. - Review of contracts and agreements to foster cooperation, e.g. divide the logging and hauling agreement into two distinct agreements to facilitate the transition from logging entrepreneurs with trucks hauling only the volume they harvested to logging entrepreneurs sharing their harvesting volume and using their truck to haul any volume - Modify accounting systems to pay loggers and truckers not on same harvested volume

Conclusion

The presentation discusses issues and solutions in the implementation of timber truck routing system. The issues can arise in the implementation of other DSSs in the wood value chain (e.g. harvesting, forwarding), making the proposed solutions valuable from the earliest development stage of a DSS to its implementation. The innovation-to-implementation learning curve, both for researchers and practitioners, is also emphasized during the presentation.

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Tactical harvest planning and forest road upgrading

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Extended abstract

Sweden has a very dense forest road network but the accessibility varies heavily. Very few roads are accessible all year around and the need for road investments, in order to secure continuous wood flow during periods of the year with low accessibility, such as spring thaw, is relevant. When and where to make road investments normally depends on the tactical harvesting planning which sets the conditions for which stands can be harvested. Skogforsk has developed a model which combines road investment activities with harvest planning using information from a tactical harvest plan over 10 years and a detailed road database. The model optimizes road investments and minimizes costs for upgrading, transportation, and storage, while the demand from saw mills and pulp- and paper mills in different seasons of the year is fulfilled. The model shows which road to upgrade to a higher accessibility class and in which season each stand is to be harvested.

The problem has a planning period of a number of years and can be positioned between long term strategic planning and annual tactical planning. The Heureka Forestry Decision Support System (DSS) (www.slu.se/heureka) is a suite of freely available software developed and hosted by the Swedish University of Agricultural Sciences (SLU) as a free service to society. The system covers the entire decision support process from data inventory to tools for selecting among plan alternatives with multi-criteria decision making techniques. The software covers stand-level analysis as well as forest-level planning and analysis. This is described in for example Edenius and Mikusinski (2009) and Lämås et al. (2006). There is currently no connection to downstream activities with a given demand description. However, in the proposed system, named VägRust, we have such a connection which will be described in this paper. The system FlowOpt (Forsberg, 2006) deals with the annual planning period and we use several parts from the FlowOpt system for integration into VägRust.

This paper deals with further development from earlier work described in Henningsson et al. (2007) and Frisk et al. (2006). The new model include different truck types, accessibility between road type – annual season (Winter/Spring/Summer/Fall), connection to Heureka's PlanWise, location of gravel supply, and a new route generator. The business decisions (to be implemented) in the model are when and how to upgrade roads and the anticipation (to model the impact of the business decisions but not being implemented through this system) variables are when harvest areas are to be harvested and transportation flows for each truck type/time period/season/road class. It is important to note that all flow variables are based on pre-generated routes. There are constraints on supply including growth models, demand at industries, transport and harvest capacities, flow balances and logical upgrading sequences. The objective is to balance costs (investment of roads, harvesting cost, transportation and inventory costs) with standing forest value at the end of the planning horizon. The model is a mixed integer programming (MIP) problem.

The results from the new model can be divided into three important parts. First, the model defines a harvesting plan where the harvested volume during each year and for each season correspond to the actual demand from saw mills and pulp- and paper mills. Second, it describes which road investments are the most cost effective in order to liberate the right amount of timber volumes. Third, it shows the allocation of timber from supply nodes to

demand nodes. This makes it possible to easily illustrate the load on different roads of importance.

The VägRust system is tested in a case study together with Sveaskog AB, Sweden's largest forest owner with 4.3 million hectares. The case study covered a total area of 6 000 km² in which 6 500 stands with an area of 70 000 hectares was a part of a tactical harvest plan. The road network owned by Sveaskog amounted to 2 500 km of which only 3% was accessible all year round. The most critical seasons of the year are spring thaw and several weeks of heavy rainfall during the fall. The case comprised of 6,544 supply areas (selected as mature for the next 10 years), 9 industries, 44,610 routes, 10 years planning horizon, 4 seasons in each year, 4 assortments and 4 group assortments, 2 vehicle types and 2,815 investable roads. The model has about 40,000 binary variables, 1.1 million variables and 0.27 million constraints. To solve the LP relaxation takes 15 minutes and to find the optimal solution takes 3 days using CPLEX.

Traditionally, it has been difficult for planners to motivate road investments, especially when the planning period is long and the number of possible investments is very high, such as in our case study. With the proposed system this is much easier. The system also makes it possible to analyze different scenarios, for example, how a longer thawing period affects the need for road investments. The long solution times can be resolved using heuristics.

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Analysis of factors that affect the transport efficiency of in-field chipping operations

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Abstract

This paper presents the results of a trial of FastTRUCK, a truck scheduling system developed by the CRC for Forestry, to evaluate some of the factors that affect transport efficiency of Australian in-field chipping operations. The analysis focused on the effect of chipper productivity and utilization, number of chipping operations accessible to each truck, truck loading and unloading time, net payload on daily transportation costs, number of trucks, and average truck utilization. According to the results obtained payload and chipper utilization are the major factors affecting transport costs. Potential savings of 52% and 29%, respectively, are possible to obtain with a better control and management of these factors.

Key words: In-field wood chipping, simulated annealing, wood supply chain, transport efficiency

Materials and Methods

FastTRUCK scheduling system

FastTRUCK uses input from the existing parameters of the transport component of an operation and generates a range of alternatives to determine the optimal (or near optimal) operating scenario (Acuna et al., 2010). Optimal truck schedules are created using a simulator and a simulated annealing algorithm. The system aims to minimize total transportation costs, and considers travel loaded and unloaded time, stood down time and fixed costs. This paper reports on a trial of FastTRUCK using the hypothetical parameters below, and examining typical operational variables.

Parameters for analysis (control scenario)

- Trucks:
 - 82.5 t GVM road trains (50 t payload)
 - Truck working shift limit: 6 h minimum to 12 h maximum
 - Average road speed 75 km/h empty and 65 km/h loaded
 - Annual freight task of 900,000 tones
 - Centrally dispatched fleet (any truck can go to any chipper)
 - Average haulage distance of 72 km with lower and upper lead distance of 29 and 150 km respectively
- Infield chippers:
 - 8 active harvest operations on single 10 h shift
 - Loading time 60 min per truck
 - Chipper utilization 90%
- Receiving facility:
 - One facility with two dumpers
 - Capacity per dumper of 250 gross metric tonnes per hour (unload up to 5 trucks per hour)
 - Facility open 14 h per day

Results and Discussion

Impact of reduced chipper utilization

Table 1 shows the effect of reduced chipper utilization. In each case the chipper was scheduled for 10 hours. There is a significant increase in the number of trucks (29%) when the chipper utilization is increased from 75% to 90%. For an annual volume of 900,000 t, an overall saving of approximately \$600,000 can be made annually for the operation presented in this example.

Table 1. Effect of chipper utilization

Performance metrics	Chipper utilization		
	75%	85%	90%*
Fleet size (number of trucks)	20	24	28
Unit cost (\$/ton)	9.49	9.71	9.90
Daily production (ton)	2,800	3,200	3,600
Average truck utilization (%)	88.3	87.6	86.4

*Control scenario

Impact of increased dispatching restrictions

Table 2 shows the effect of restricting the number of in-field chipping operations an individual truck can service. For an annual volume of 900,000 tons, using multiple destinations (determined optimally by FastTRUCK) can save more than \$234,000 in transport costs for the operation presented in this example.

Table 2. Effect of the number of operations available to service by each truck

Performance metrics	Number of in-field chipping operations available to service		
	1	2	Multiple*
Fleet size (number of trucks)	30	29	28
Unit cost (\$/ton)	10.16	10.03	9.90
Daily production (ton)	3,600	3,600	3,600
Average truck utilization (%)	87.9	87.0	86.4

* Control scenario

Impact of increased loading times

Table 3 shows the effect of loading time. Increasing the loading time from 50 min/truck to 60 min/truck results in an increased cost of \$0.39 / t or \$351,000 per year. A further rise in loading time from 60 min/truck to 70 min/truck results in a reduced cost per ton (compared to 60 min loading time) due to the substantial reduction in the fleet size.

Table 3. Effect of loading time

Performance metrics	Loading time		
	50 min/truck	60 min/truck*	70 min/truck
Fleet size (number of trucks)	29	28	21

Unit cost (\$/ton)	9.54	9.90	9.73
Daily production (ton)	4,000	3,600	2,800
Average truck utilization (%)	87.7	86.4	88.2

* Control scenario

Impact of payload

Table 4 shows the effect of net payload. Increasing the payload from 47 tons to 53 tons results in a reduction of transport costs by \$1.2 per ton or \$1,080,000 per year for an annual volume of 900,000 t. These results are consistent with those obtained in previous studies carried out by the CRC for Forestry (Brown, 2008).

Table 4. Effect of net payload

Performance metrics	Net payload		
	47 tons/truck	50 tons/truck*	53 tons/truck
Fleet size (number of trucks)	28	28	28
Unit cost (\$/ton)	10.53	9.90	9.34
Daily production (tons)	3,384	3,600	3,816
Average truck utilization (%)	86.4	86.4	86.4

* Control scenario

Conclusions

- The impact of operational factors on transport costs and opportunities for improvements can be determined by using optimal scheduling systems such as FastTRUCK.
- Large savings in transport costs are possible without a major shift in technology by optimizing truck schedules, maximizing payload and improving the efficiency of chipping operations.
- Payload and chipper utilization are the major factors affecting transport costs. Control and improvement of these factors accounted for 52% and 29% (respectively) of the potential savings obtained.

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Controlling a link of a wood value chain: Activity-based costing in pulp mills

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Introduction

In the cut-to-length harvesting method, the bucking decisions are made with the demand information of each timber assortment in the wood conversion industry (Uusitalo 2005). The demand of each timber assortment is eventually determined at the mill-level production planning according to contracts and markets. Mill management must make calculations and have unbiased information of the market prices, demand of end products and the cost structure. The cost structure of the mill is the noteworthy variable in the equation, since it can be affected.

Forestry researchers in Finland have focused studies more to supply chain management research (Nurminen et al. 2006, and Nurminen et al. 2009). These studies have concentrated on the logistic modeling for the raw material delivery to factories. However, these upstream models need input data from the production and downstream flows for efficient resource planning (Hsu & Hsu 2008). In the cut-to-length-based wood procurement chains, the tree bucking decisions are dependent on the value of each timber assortment (Uusitalo 2005). This value should be derived from the wood conversion industry and actual profit-based calculations.

The aim of this research was to develop and test a cost model for predicting the production costs of a large-scale kraft pulp mill, which is located in a Nordic country. We also tested the model with two different pulpwood sources.

Materials and methods

We studied the processing costs of chemical pulping, determined an activity-based costing (ABC) model for a standalone virtual kraft pulp mill, and tested the model in Nordic conditions. ABC is accurate and adaptable costing method, which allocates costs to products according to the consumption of production resources (Turney 2005). The ABC has already been tested successfully in wood conversion industry by Korpunen et al (2010). The virtual pulp mill was “built” with information (production, price and technical) derived from interviews and general statistics. Annual production of the pulp mill was determined to 700000 Air-dry tons (Adt), and the wood raw material was Scots pine. If the pulp is produced from wood material, which are butt logs from thinning (basic density of 376 kg/m³), the amount of produced pulp refers approximately to 5,087 million cubic meters of roundwood with bark. If the pulp is produced from top logs from clear cuttings (basic density of 361 kg/m³), the amount of wood needed increases to 5,298 cubic meters.

Results

The pulp was produced in two main processes: wood handling and pulping. The mill also had drying and supporting departments as separate processes. The wood handling started from the receiving, unloading and debarking of logs and ended with chip storing. The pulping was considered to start from the cooking and in-digester washing and ended with the bleaching of the pulp. Drying was the last actual pulp production process; the supporting departments handled the chemical recovery and energy production of the mill. The processes are

presented in the total cost distribution pie chart in figure 1. The virtual pulp mill had annual production costs of 110 million Euros and the amount of labor was 86.5 person-years.

Pulpmilling case:

A greenfield kraft pulpmill, for Scots pine.
Annual roundwood consumption 4500000 m³.

Pulp production 700000 Adt.
Other end products: Turpentine, crude tall oil, heat energy and electricity

Bleaching: D-EOP-D-D, Kappa number after O²: 12.

Labour force: 86,5 person-years

Total annual processing costs: 110 M€

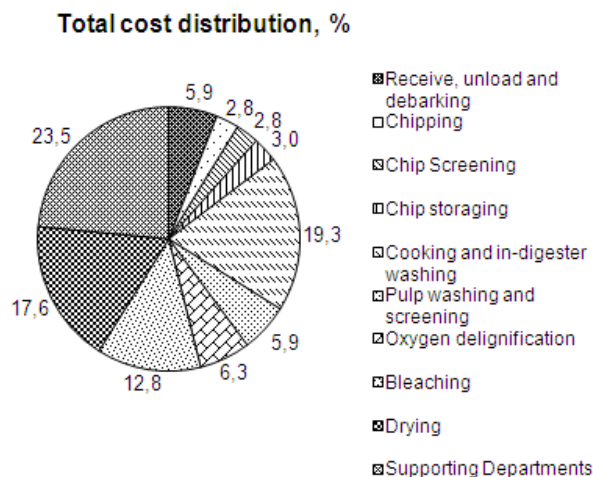


Figure 1. The cost distribution in kraft pulp mill.

If the production costs were allocated to roundwood from butt logs (basic density of 376 kg/m³), the cost per cubic meter was 21.6 €/m³. If the wood was from top logs (361 kg/m³), the unit production cost was 20.76 €/m³ for logs.

Discussion and conclusions

The difference in production costs between the butt logs and top logs was approximately 4 percent. The cost model does not cover all of the differences caused by the two different raw materials. For example, the chemical costs may vary because the basic density of wood correlates with other essential wood properties (e.g. extractives). However, the importance of the chemical costs is not crucial, as the pulp industry has high rate of fixed costs. The production costs of the supporting departments were the highest, but the chemical recovery and the energy production eventually become very important for the profitability of the chemical pulp mill.

Even though the production costs are not differing more than 4 percent between raw materials, the variation in basic density causes difference of roughly 200,000 m³ in annual logging, which equals a logging capacity of approximately five cut-to-length harvesting chains. However, variation in annual logging is probably more important for entrepreneurs than for the pulp mill.

The ABC method is suitable for pulp manufacturing: the process-based method allows for the monitoring of the value adding at each phase of production. Since the constant improvement of the production is the essential part of the modern business culture, the efforts can be allocated accurately for the best economical result. By combining the incomes and pulpwood procurement costs with production costs, the entire pulpwood value chain can be controlled and directed for best profitability in the future.

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Optimization of the forest fuel supply chain in Sweden.

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Extended abstract

Forest biofuels are an important part of the energy production in Sweden. The oil crises in the mid 1970's made it clear that Sweden needed to secure a domestic supply of alternative fuels. Later, environmental goals, most recently climate change, have become part of this rationale. Sweden currently bases 20-25% of its energy systems on forest biomass. This parallels the overall EU goal to have 20% of the energy production coming from bio-fuels by the year 2020. The number of heating plants and their use is increasing in Sweden. Heating plants provide heated water through a pipe system to apartments and houses. In many cities, a majority of the population uses this heating system. Moreover, there is also a strong development of so-called CHP plants for combined production of both heat and electricity.

The growing use of forest fuels for energy production increases the need of effective planning systems to manage and plan the forest fuel supply chain. It includes decisions of how, when and where to comminute (or chip) the logging residues, when and where to store it and how to transport it to terminals and heating plants. As there are many systems in use, it is important to balance their capacities over the season. Furthermore, the procurement cost at harvesting sites and price level at the customer have to be taken into consideration.

The Forestry Research Institute of Sweden (Skogforsk) has developed several DSS for the forest supply chain of roundwood for both tactical and strategic transportation and harvesting planning, see Karlsson et al. (2004), Forsberg et al. (2005), Frisk et al. (2006), and Andersson et al. (2008). One of the systems is FlowOpt (Forsberg et al., 2005). This is a DSS for strategic and tactical management of roundwood procurement and has been used in many case studies at Swedish and international forest companies. The main questions to be answered in FlowOpt concern allocation of timber, back hauling possibilities, location of train terminals and cooperation between companies. FlowOpt uses different transport modes in the optimization such as truck, train and boat.

Skogforsk has in the past few years collaborated with the companies Holmen Skog AB, Sveaskog AB, Stora Enso Bioenergy and further developed FlowOpt into the system FuelOpt, which includes procurement of forest fuels. Forest fuel procurement comprises more variation in the supply chain than roundwood procurement since there are extra decisions to be made. The optimization model used in the system has therefore been further extended to manage the various decisions that are needed for forest fuels. The decisions include when and where to allocate the logging residues and what kind of system of allocation should be used. Given the choice of machine systems, there are constraints on capacity for both allocation and transportation. The new model also compares costs for purchasing residues and the value of the product when it is delivered to the customers. The objective is to either minimize the costs for a given demand or to maximize the profit with a minimum demand level but with the possibility to still supply extra. The system is developed around a flexible platform in regards to input data and view results in maps, reports etc. It uses the Swedish National Road database to generate all necessary distances.

We have tested the system on two large case studies. A first case study has been done together with the major Swedish forest company Sveaskog, which handles approximately 2 TW of forest fuels every year. The planning horizon for this case is one year and the case

covers forest fuel handling in the middle of Sweden, where supply was grouped into 400 supply points with 800 GW of forest fuels. There are eight assortments and 15 terminals. The demand occurs at 21 heating plants and corresponds to 600 GW with the possibility for Sveaskog to deliver more if profitable. Several machine systems are used for chipping and transportation.

A second case study is with the company Stora Enso Bioenergi AB, which is the largest company dealing with forest fuels. The planning horizon is one year and the area covers the same region as Sveaskog, but extends down to southern Sweden. As such, the area is about three times larger. This case has 86 heating plants with a total demand of 3.6 TWh, corresponding to about 1.5 million metric tons. There are six assortments, five different chipping systems, six truck types and 27 train systems in use. The supply is grouped into either 233 or 1256 supply points depending on the aggregation levels. There are 72 terminals used for storage and allocation. The results show that the system can be used for both tactical analysis and planning for the next year.

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A transport tool to measure sustainable impacts of transport processes within the forest wood chain.

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Context and objective

Measurement of sustainability of the forest based sector is of major concern as the sustainable paradigm is becoming the norm. Within the EFORWOOD project (2005-2010), the ToSIA (Tool for Sustainable Impact Assessment) was developed in order to assess the sustainability impacts of this sector. ToSIA is a software tool designed to analyze and compare several Forest Wood Chains (FWCs) alternatives under economic, social and environmental dimensions. In EFORWOOD, FWCs were defined “as chains of production processes which are linked with products”. Many processes defined within EFORWOOD are related to transport which appears along the whole chain involving several types of transport modes and categories of equipment. The goal was to set-up a common approach for all the transport processes throughout the chain. This led to an “ad hoc transport tool” designed to estimate some impacts.

Materials & methods

A value chain approach involves identifying and quantifying the sustainability impact of transformation and distribution processes which compose the chain. The aim is not to provide solutions to improve the sustainability of each process, but simply to give detailed “photography” of the chain and its processes.

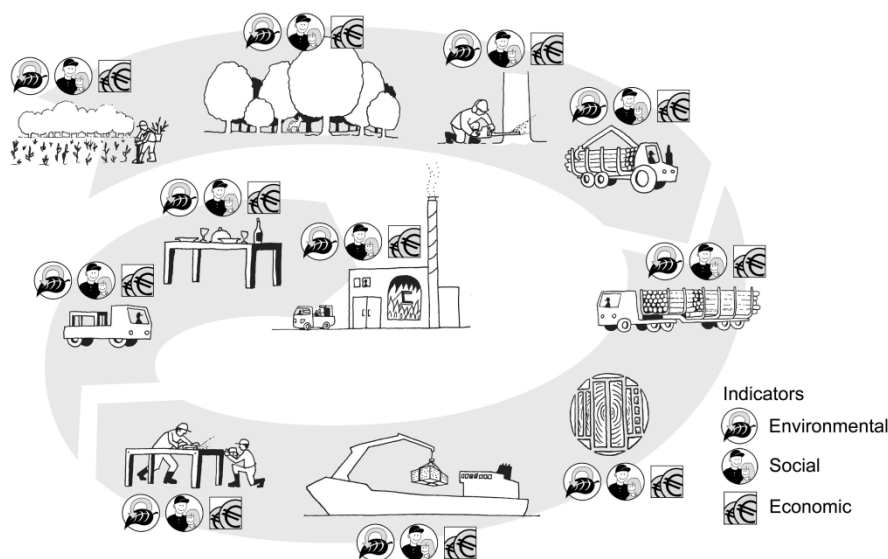


Figure 1: The Forest Wood Chain in the EFORWOOD project (Source: Lindner et al. 2009)

The “logistic” approach is useful for increasing the efficiency of transport processes but not necessarily for quantifying their sustainability impacts. Therefore, the tool is mainly transport oriented but includes some logistics’ dimensions at a macroscopic level (empty back-haulage rate) or specific to the product carried (loading rate).

The tool has been designed to fit ToSIA by compiling/adapting transportation and sustainability assessment works and existing tools (ex. Bilan Carbone®, Promit). It has also been set-up first, to allow the calculation of major sustainability indicators related to production costs (labor, energy, other productive and non-productive costs) and employment,

energy use with GHG and non GHG emissions (NOx, SO2 and CO), transport intensity and modal split through distances per mode; second, to cover or limits the risk of low data availability (Eurostat basement).

Results

The transport tool allows evaluation of the impacts of the transport processes. It is fairly easy to use, requests very few input data fields and provides indicator values for all transport processes in each European FWC. Feeding ToSIA, it can also be used and developed for different stakeholders: transport enterprises, industries or authorities as a support for assessing opportunities and impacts of alternatives to existing logistics chains.

WERTRANSPORT TOOL

UserForm1

FCBA
INSTITUT TECHNOLOGIQUE

Input Data

Compulsory data

Country:

Product type:

Vehicle type:

Type of fuel:

Inclusion of Loading/Unloading costs (only for Production costs):

Complementary data

If these data are not provided, national average data (Eurostat) will be used by default.

Total distance (in km):

Road distance (in km):

Rail distance (in km):

Inland Waterways distance (in km):

Road vehicle only

Loading (in tonnes):

Emptybackhaulage rate (in %):

Validate

Results

Indicators are reported per tonne of products carried

Socio-Economic Indicators

Production costs: €

Labour cost: €

Energy costs: €

Other productive costs: €

Non Productive costs: €

Employment: Abs Nb

Environmental Indicators

Energy use (fossil fuel): MJ

Energy use (electricity): kWh

Green House Gas Emissions: kg CO2

CO Emissions (diesel only): kg

NOx Emissions (diesel only): kg

SO2 Emissions (diesel only): kg

Transport Indicators

Road distance loaded: Tkm

Road distance unloaded: km

Rail distance loaded: Tkm

Inland Waterways distance loaded: Tkm

Economic data related to Rail and Inland Waterways have to be taken cautiously as they are subject to certain assumptions

EFORWOOD

démarrer

Citrix Client Engine

Citrix XenApp - Applic...

EN FR

16:51

Discussion and conclusion

The tool can be used to compare transport processes within the FWCs or between countries under the sustainable dimension. The methodology and the data used to set up this tool are not exclusive or fixed. Indeed, logistics variables can be changed by tool users and as default values are only based on products densities. The tool will be used for instance within the European project (FP7) "Boosteff" for "Boosting raw material and energy efficiency using advanced sheet structure design and fiber modifications" (2010-2013) to evaluate the transport dimension of the change of the inputs' composition on the overall environmental footprint.

The tool has several limitations which should be pushed aside with new developments:

- The valuation of rail and inland waterways costs and loading/unloading costs still requires an improvement in the data collection and in the methodology.
- Maritime transport is not covered by the tool.
- The tool is not related to geographical data. A development of interest would be its use through a Geographic Information System (GIS) system, involving a higher level of detail with the inclusion of time/speed dimension in the indicators measurement. As such, GIS would allow identification of several levels of speed through speed limits per road category and several levels of fuel consumption.

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Keywords: Transport, Forest Wood Chain, Sustainability Impacts, Indicators, Logistics.

Integrated versus decoupled planning in the forest value chain

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Extended abstract

The forest value chain (VC) in the forest industry starts with harvesting operations where different log types (for example saw logs, pulp logs and fuel logs) are produced in the bucking process. The logs are defined through attributes (for example species, grades, dimensions, etc.) and volume proportions are based on tree characteristics (for example age, diameter, length and location). Logs are the raw material for the primary transformation mills, which produce final or intermediate products (for example lumber, plywood, pulp, energy, etc.) for customers and secondary transformation mills. It is important to note that the VC is a divergent chain with one-to-many processes. Hence, the coordination and the planning of the VC can produce many diverse outcomes according to the strategy used for managing it. A recent description of the forest supply chain and planning problems is found in D'Amours et al. (2008).

In this paper, we are interested in comparing two different planning strategies. In the first strategy, the planning of the forest and the industry is decoupled and planned in a sequential approach. The forest is planned first with the objective of maximizing the expected net present value of timber, and the industry is planned second, with the objective of maximizing the actualized profits constrained by the availability of the logs. The first part covers a planning period of at least one rotation (for example 25 years) whereas the second cover a shorter period (for example five years) where the demand can be estimated. We will use the notation business planning period for the shorter horizon. This approach can be viewed as a decoupled strategy where logs become available for further transformation. It is compared with an integrated strategy where all parts of the value chain (forest and mills) are driven by both a final product demand over the business planning period and an estimation of the forest value over the remaining period, and where the objective is to maximize the total expected long term profit of the company. The main difference between the decoupled and integrated approach is how the VC planner uses the demand information and plans simultaneously the different activities. Under the decoupled strategy, the forest manager plans the harvesting and log transportation activities in order to optimize an expected net present value of the logs.

In the integrated strategy, the forest planning is driven by demand of final products and all value chain activities are synchronized to maximize profit and to respond to the estimated end product demand (Giunipero et al., 2008). The forest value chain has traditionally been managed under a decoupled strategy as forest companies have not thoroughly integrated the forest planning with the industrial logistic and production planning. In the same manner, the logistics and production planners have used the availability of logs as a constraint without any possibility to alter. The literature shows multiple optimization models developed for forest management planning, with some models supporting decisions such as: which silviculture regimes to apply in a forest, which stands to harvest per time period, what is the optimal rotation age, etc (Gunn, 2007). Some of these models also aim to support short term harvesting decisions and timber production decisions (Epstein et al., 2007).

Not integrating forest and mill decisions leads to sub-optimality, as mills cannot optimize benefits because they need to adapt their production process to the available logs at a specific time. As the planning process is carried out, present forest managers plan harvest and bucking operations based on transfer prices received for each product. In addition, there may be a minimum supply to mills based on their basic contractual needs. This leads to situations where managers at mills receive logs that are not the best fit for the demand they face in terms of specific boards to be produced (Weintraub et al., 2000).

The main contributions of this paper are the following: First, we propose an integrated planning strategy and a generic MIP model that solves the integrated problem. Second, we make an analysis between the traditional decoupled strategy and show that the integrated strategy is more efficient in terms of both NPV value and profit. A case study from Chile is used to analyze the two approaches. The case study includes 1226 harvest areas, five mills, six log types and four products. The total planning period is 30 years with a five year business period.

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Multi-objective decision model for supplying wood biomass feedstock to power generating stations in northwestern Ontario

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The Provincial Government of Ontario decided to stop coal burning in its power generating stations by 2014 in order to reduce greenhouse gas emissions. One of the alternatives for running the generating stations is to use wood biomass feedstock to produce power. The decision has been made to run four power generating stations in northwestern Ontario by wood biomass feedstock. The generating stations are: Abitibi-Bowater Power Plant in Thunder Bay with the production capacity of 61 MW; Abitibi-Bowater Power Plant in Fort Frances with the capacity of 50 MW; Atikokan Generating Station in Atikokan with the capacity of 227 MW; and Domtar Power Plant in Dryden with the capacity of 30 MW. There are twenty forest management units in northwestern Ontario. These are as follows: Crossroute Forest, Wabigoon Forest, Sapawe Forest, Dog-River Matawin Forest, English River Forest, Spruce River Forest, Lakehead Forest, Black Sturgeon Forest, Whiskey Jack Forest, Kenora Forest, Lac Seul Forest, Caribou Forest, Trout Lake Forest, Red Lake Forest, Armstrong Forest, Dryden Forest, Ogoki Forest, Lake Nipigon Forest, Kenogami Forest, and Pic River Ojibway Forest. There are two main types of wood biomass feedstock available in these forests, including forest harvest residue and non-merchantable wood. The wood biomass feedstock can be supplied from these forest management units to these power generating stations to produce power.

The main challenge within the wood biomass supply chain is to develop a strategy to select the type and amount of wood biomass feedstock from a specific forest management unit in order to produce power with minimum costs depending on both the demand and the distance of the power generating station from the source of wood biomass. Different criteria or objectives need to be taken into consideration to produce power in a sustainable way as one particular criterion or objective alone cannot solve this complex problem. A multi-objective decision making model is being developed for supplying wood biomass feedstock to power generating stations in northwestern Ontario. The selected criteria for this model are as follows: wood biomass feedstock procurement cost, quality of feedstock, lead-time and transportation cost.

The pre-harvest inventory and the post-harvest inventory were conducted in the field to find out the available biomass within forest management units. The main factors considered to estimate the quality of wood biomass are as follows: moisture content, tree species, rock and other impurities availability in wood biomass feedstock, duration and types wood biomass storage, and types of wood biomass. Spatial data analysis was done using ArcGIS software and Visual Basic software. Using ArcGIS, three database layers were developed for the whole extent of the research area, namely, Roads, Landuse Class and Forest Depletion. Data input methods used for establishing these layers were as follows: precedence/absence methods for roads, dominant type for landuse class and percent occurrence for forest depletion layer.

By using these databases, different variable transport cost zones surrounding each of the power generating stations were established with the help of program in Visual Basic software. The variable transport cost zones are as follows: 0-5 \$/Gt, 5-10 \$/Gt, 10-15 \$/Gt, 15-20 \$/Gt, 20-25 \$/Gt and 25-30 \$/Gt. Using the field data and the spatial data, a multi-objective decision making model is being developed with LINGO11 software. A Value Path Analysis is being conducted by giving priority to each of the criteria. Using this method,

economic wood biomass supply zones for each of the four power generating stations of northwestern Ontario are being developed for the purpose of supplying wood biomass feedstock in an economically feasible and sustainable way.

The main purpose of the multi-objective decision model is to decide from which forest management unit how much and which types of wood biomass feedstock are necessary to be collected, per month, to feed each of the power generating stations of northwestern Ontario. At the same time, minimum costs have to be occurred and the production must be sustainable. The research finding ensures that there is enough wood biomass feedstock in northwestern Ontario within the economic distance of four major generating stations to run these stations in an economically feasible and sustainable way. This multi-objective decision model will be helpful for the forest industries across Canada and abroad to run profitably, as the model captures different important criteria to obtain the optimal solution of supplying wood biomass feedstock with minimum cost for energy production.

Integrating Product and Market Information into the Value Chain: Stand Product Potential Geo-database for Northwestern Ontario

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Supply chain optimization research is becoming increasingly important in the global bio-economy. The ability to track and optimize resources from the forest to end-user will determine the groups who will remain competitive in future years. Having an enhanced forest inventory, based on value rather than merely volume, is an important knowledge gap in value chain research. Accurate estimates of fiber volume, quality, and potential products from the forest inventory, are the foundation to optimizing bio-economy value chains.

The purpose of this research program is to build an information-tracking framework that can be used to optimize forest fiber by linking tree quality characteristics to product lines to create a Stand Product Potential (SPP) geo-database for northwestern Ontario. The specific objectives of the study are: (i) to link sawmill log scanning information back through the supply chain to determine stand and tree characteristics that most significantly impact product quality, (ii) to develop regression models to estimate SPP in forest stands, and (iii) to develop a prototype framework integrating the matrix of potential products and associated values of a stand into a geodatabase for strategic forest management.

Three mixed species sites in northwestern Ontario were harvested using a conventional mechanized full-tree system. 500 m³ of jack pine, tree-length logs from each site were delivered to a Thunder Bay sawmill. The jack pine volumes from each site were processed independently through the sawmill after all logs, lumber and residue were purged from the saw lines, and all the computers scanning information were zeroed. Information was tracked at each stage of the wood procurement and conversion process up to rough green lumber production (Table 1). The datasets collected for each site included a timber cruise (stage 1), tree-length taper and quality profiles (stage 2), site and mill recovery volumes and product (stage 3), residual biomass and standing tree volume (stage 4), and internal fiber properties of sample jack pine trees (stage 5).

The study tests whether an enhanced forest inventory can be correlated with sawmill production data to give estimates of forest stand value before harvesting. In order to understand the relationship between stand variables and product creation at the sawmill, the data has been backtracked from rough green lumber production to pre-harvest cruise information. The study uses principle component analysis (PCA) to reverse engineer mill production data back to the stand level description data in order to reveal stand level factors that most significantly impact sawmill value production. The analysis technique presented in this study will develop the methodology for future studies to build a comprehensive SPP geodatabase for northwestern Ontario.

Data summaries have been produced for each stage of data collection. More detailed results will be presented along with the PCA procedure to relate stand characteristics to log sizes and lumber value creation. The factors generated from the PCA will provide a novel methodology by which to guide future work in predicting value yields from forest stands. Research in predicting value yields from stands will be expanded to using remote sensing techniques. The study will reveal the most significant stand level factors capable of predicting product mix and value, as well as propose a framework to integrate this data into forest management planning software for strategic and tactical planning.

In order to integrate wood-flow logistics and market intelligence to meet market demands in forest value chains, the tracking of fiber quantity, quality and value from standing timber to primary product creation is imperative.

Table 1. Description of data variables collected at each stage of the study.

Stage 1: Timber Cruise	Stage 2: Tree-Length	Stage 3: Mill Recovery	Stage 4: Residual Biomass	Stage 5: Internal Properties
<p>Objectives:</p> <ol style="list-style-type: none"> 1. Establish georeferenced timber cruise plots (BAF4) to record stand volume and quality parameters. <p>Data Collected:</p> <ol style="list-style-type: none"> 1. Plot Profile <ul style="list-style-type: none"> • Aspect • Slope • Ecosite • Crown closure • Dominant species age • Azimuth and distance to each tree from plot center 2. Tree height at: <ul style="list-style-type: none"> • Top • 1st dead branch • 1st live branch • Top merchantable height 3. Diameter at: <ul style="list-style-type: none"> • DBH • 2.5m increments 4. Visual quality defect: <ul style="list-style-type: none"> • Heart rot • Ridge • Crook • Sweep • Snapped top • Fork • Frost crack • Mechanical damage • Scar • Snag 5. Defect severity: 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. Record stem taper and quality profiles of tree-length logs at roadside. <p>Data Collected</p> <ol style="list-style-type: none"> 1. Length-diameter measures: <ul style="list-style-type: none"> • Diameter at: base, DBH, 2.5m increments, top 2. Branch measures: <ul style="list-style-type: none"> • Max branch diameter at each 2.5m increment 3. Visual quality defect: <ul style="list-style-type: none"> • Heart rot • Ridge • Crook • Sweep • Snapped top • Fork • Frost crack a. Mechanical. damage • Scar • Snag 4. Defect severity: <ul style="list-style-type: none"> • Scale 1-5 (1 is barely noticeable, 5 is non-merchantable) 5. Defect range: <ul style="list-style-type: none"> a. Start and stop position on tree-length 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. Track volume (chips and sawlogs) by species. 2. Pull detailed lumber recovery files from mill scanners. <p>Data Collected:</p> <ol style="list-style-type: none"> 1. Tree-length and chip <ul style="list-style-type: none"> • Weigh-scale reports from sawmill and pulpmill 2. Tree length to log scale: <ul style="list-style-type: none"> • Tree length • Size of logs recovered • Quality of logs recovered 3. Optimization sawing scanners: <ul style="list-style-type: none"> • Date & time • Log diameter small • Log diameter large • Log length • Log volume • Sweep • Taper • Log grade • Lumber of pieces in log • Individual piece volume, grade • Lumber recovery value for log • Primary lumber recovery 4. Waste and Residue data: <ul style="list-style-type: none"> • Volume (end pieces, chips, sawdust) 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. Record residual biomass and standing tree volume. <p>Data Collected:</p> <ol style="list-style-type: none"> 1. Ground biomass transect method: <ul style="list-style-type: none"> • Length • Diameter • Species • Type • Quality 2. Residual standing trees using BAF 2 prism method: <ul style="list-style-type: none"> • DBH • Height • Species • Quality 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. Determine strength properties in jack pine sample trees at each site. <p>Data Collected:</p> <ol style="list-style-type: none"> 1. Full log measurements of sample trees: <ul style="list-style-type: none"> • Same measurements as stage 2 2. Bolts (1m) cut from 0, 25, 50, 75, and 100 percent of merchantable stem (top diameter 10cm outside bark: <ul style="list-style-type: none"> • MOE • MOR • Compression • Density 3. Disks cut at 2.5m intervals for ring growth and density profiles pith to bark: <ul style="list-style-type: none"> • Early wood/Latewood diameters • X-ray densitometer profile from pith to bark <p>Objectives:</p> <ol style="list-style-type: none"> 1. Determine strength properties in jack pine sample trees at each site.

A SCOR-based framework to portray a wood supply system – Presentation and application in wood supply chain of different countries

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The objective of the EU-funded FlexWood (Flexible Wood Supply Chain) project is to design an innovative wood supply system (WSS) that increases value recovery along the wood supply chain (WSC). The "FlexWood WSS" is based on the development and adaptation of logistics concepts that provide better information assessment on wood resources (e.g. aerial and terrestrial laser technologies), enhance optimization models, and increase flexibility and tailoring capabilities. For more details, see: <http://www.flexwood-eu.org>.

The work presented in this paper is a work package within FlexWood. It aims to develop a generic framework to describe and represent any WSSs. Important aspects addressed within the framework are agility (e.g. Li et al. 2008), competitive advantages (e.g. Li et al. 2006 and Lakhali 2009) and customization options (e.g. Poulin et al., 2006) using supply chain performance metrics (e.g. order fulfillment cycle time) and statements evaluation on a five-point Likert-type scale. By using such a framework to study the WSS of WSC in different countries, basic configurations and competitive strategy of WSS and the used logistics concepts will be identified. This development will support the design of the "FlexWood WSS".

In this paper, we present the first version of the framework. It is based on a forestry adaptation of the well-established SCOR (Supply Chain Operations Reference) model by the Supply Chain Council (SCC, 2008). A first attempt on the SCOR model adaptation in forestry has been made by Schnetzler et al. (2009). Business entities (from both private and public sectors) involved in the WSC deal with all activities from forest inventory to raw material delivery at the mills. They are responsible for operational planning as well as executing the processes in order to fulfill and manage the demand with the supply. The business entities and the processes are illustrated in the framework. Information, material and financial flows among the business entities and their coordination mechanisms (e.g. verbal or formal written agreement) are also captured in the framework. Moreover, the framework locates the commitment point(s) and the customer order decoupling point(s) in the WSC. The latter point defines the boundary between the push and pull approaches. The consequences (e.g. constraint, opportunity) of decisions taken upstream of the operational level are also emphasized.

The results of the framework application on WSCs in three countries are presented. The configuration and competitive strategy of each studied WSS, the logistics concepts used, their level of integration and collaboration and the dominating planning strategy of the WSC are reported. Also, each studied WSS is analyzed regarding its positive and negative impacts on agility, competitive advantages and tailoring capabilities.

Acknowledgements:

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Airborne laser scanning and harvester measurements for pre-harvest planning

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Introduction

In order to implement modern tools for optimized wood flow based on industrial requirements, there is a demand for accurate, high-resolution data from pre-harvest inventories. Today, most planning in practical forestry is based on stand records or pre-harvest field inventories, which normally are based on the stand average. Accurate predictions of roundwood product recovery require information on individual stem geometric attributes, e.g. diameters and height, as well as tree species and information of stem defects. Inventories based on airborne laser scanning (ALS) are already used in operations in Scandinavian forestry to predict stem attribute data (Barth et al. 2008). Estimates of stem attributes are based on models requiring ground based field inventories which are expensive, although only require a few manual measurements of each sample stem. Stem diameters and length measurements from CTL-harvesters are already available; this information can be used to establish estimation models. Additionally, harvester measurement data gives information on stem taper for individual trees. A recent study shows that this method yield similar levels of accuracy in estimating tree height, DBH, and stem volume when compared to models based on sample plot data (Holmgren et al. 2010).

Objectives

In this study, forest data based on two different methods was used as input to estimate roundwood product recovery from 17 stands. The methods were based on the following: i) ALS trained by harvester data and ii) ALS trained with sample plot data. In these first results, only the geometric estimations of the stems were considered in the analysis; however, in practical bucking simulations frequencies of stem defects have to be considered as well.

Materials and methods

Forest data came from a test site in northern Sweden (64° 6' N, 19° 11' E) where 17 forest stands, already planned to be harvested, were selected. The forest stands were dominated by either Scots pine or Norway spruce. Four field plots within each forest stand were systematically placed on a grid with 50 m inter-node distance.

Two different methods were used to provide the round-wood product recovery analysis with forest data:

1. **ALS data trained with harvester measurements**

High resolution ALS data was used as carrier data, linking information from harvested trees to trees that was planned to be harvested. The method provides estimates of stem diameters at every 10 cm and tree height for each ALS detected tree. A comprehensive description of the method is described in Holmgren et al. 2010.

2. **ALS data trained with sample plot measurements**

High resolution ALS data was used as carrier data, linking information from field callipered trees to trees that was planned to be harvested. For each ALS detected tree,

stem diameter at breast height and the height of the tree was estimated. General stem taper functions were used to provide diameter for each 10 cm height of the tree.

Product recovery analyses were performed with Aptan (Arlinger et al. 2002). Simple price matrixes for bucking were used, including only two products per tree species. No stem defects were considered in the analysis. Also the stem-files from the actual harvested trees were used as input in Aptan. These results were considered to be the true product recovery for each stand. Validations of the two methods were made on stand level and based on comparison between the true product recovery and the product recovery from the analyses based on ALS data. The average deviation and RMSE were calculated using Equations 1 and 2, where y_i is the predicted variable for stand i and N is number of stands.

Eq. 1:
$$D_{avg} = \frac{1}{N} \sum_{i=1}^N y_i - y_i$$

Eq. 2:
$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (y_i - y_i)^2}$$

Results

Product	Method 1 (ALS & harvester)		Method 2 (ALS & field plots)	
	D_{avg}	RMSE	D_{avg}	RMSE
Saw timber	-5.8 (-1.5 %)	29.0 (18.6 %)	-14.0 (-6.7 %)	31.5 (19.6 %)
Pulp	0.2 (5.9 %)	11.6 (26.7 %)	-1.8 (0.3 %)	11.0 (22.2 %)
All	-5.6 (-1.9 %)	25.9 (11.8 %)	-15.9 (-7.0 %)	28.7 (13.1 %)

Discussion

The two inventory methodologies evaluated are very similar when comparing geometric attributes as input in product recovery analysis. The most important difference is which method has been used to establish the stem taper function. ALS data trained with sample plot measurements are similar to the most developed methods used in practical forest inventories today. The method based on harvester measurements does not require any stem taper function to be used in the product recovery analysis. Additionally, general frequencies of stem defects, such as root rot, can be provided from harvester data. Analysis of aggregated stand average values as input in product recovery analyses will be provided.

Conclusion

Field measurements are required when ALS data is used to estimate timber related attributes. Measurements from harvesters can replace expensive sample-plot inventories in pre-harvest inventories when ALS data is used. In the Swedish case, when stem taper functions are available, stem taper information from the harvester seems to have limited contribution.

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The importance of economic and environmental assessment of roundwood transportation in the forest wood chain

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The transport of roundwood from the place of origin (forest) to the point of first conversion (mill gate) is technically and economically challenging, given the fact that the source of origin is very dispersed, changes with time and that roundwood is a bulky product with a relatively low weight to volume ratio. Wood transport is carried out with special trucks in most cases, which hampers the organization of back-haulage. The related costs as well as the environmental impacts (emissions, fossil energy consumption) are in conflict with an otherwise positive eco-profile of wood and wood products. For these reasons, sawmills try to organize their roundwood supply chain in a way that minimizes transport distances.

In the southern part of Germany, the average transport distance of sawmills ranges between 70-120 km (one way distance). Increasing mill capacities in the last decade generally lead to increased transport distances. Long distance transport is already common today when it comes to “unplanned” roundwood supply, such as due to large windthrow events, which are more and more frequent in the last decades. These catastrophic events result in large quantities of lower priced roundwood at the market. To absorb these quantities, long distance transport of roundwood is organized, which can range between 300 and 1000 km, depending on the distance from the windfall to the respective mill.

It is believed, that over a certain transport distance, railway and ship are superior to truck transport in both, economic and ecological aspects.

Case study Kyrill

The last big storm event in Germany, named Kyrill, blew down an estimated 37 million m³ roundwood volume on 18th/19th January 2007, nearly 16 million m³ of which on a cleared area of 30.000 ha in North Rhine-Westphalia in the central west of Germany. A big sawmill X in southern Germany purchased a total of 57.000 m³ from this area. The air-line distance between the windfall area and the sawmill was approximately 400 km.

As sawmill X is situated relatively close to a railway line and to a fluvial harbor, they organized the transport so that 43.000 m³ were transported by ship via channels and rivers and 14.000 m³ by railway. All relevant data for these transports were recorded in detail.

Another sawmill Y in southern Germany, located far away from any river and railway line, had also purchased roundwood from the same windfall area, and organized their transport entirely by truck. Also for this transport alternative, the relevant figures were recorded as real data.

These two data sets allowed a comparative analysis. For sawmill X the (real) data for ship and railway transport were compared to a “virtual” truck transport of sawmill X, modeled with real data of sawmill Y.

The objective was to analyze and compare both economic and environmental parameters for an alternative rail/ship/truck transport from the windfall area to mill X.

The following criteria were selected: transport distances for the different means of transportation, total transport costs at mill gate, energy consumption and the related total CO₂ and NO_x emissions for the alternative chains. The reference unit was one m³ roundwood (fresh). Included into the system boundaries were all transport costs and the direct energy consumption and emissions related to the means of transportation. For all truck transport phases empty back haulage was included. Also, the energy consumption and emissions of the pre-chains to produce diesel for trucks, ships and railway and electricity for railway were included. Not included were the material and energy input for construction and the maintenance of the transport means as well as the energy input, emissions and costs for traffic infrastructure (building, maintenance and management of roads, railway lines, rivers and fluvial channels).

The following data was directly collected at mill X and Y respectively: volumes and tonnage of the transported roundwood, conversion factors from volume to weight of roundwood, distances, costs, fuel consumption of the trucks. Standard data from environmental data banks (Ecoinvent, EcoTransIT, HBEFA) were used to calculate the energy consumption of ship and railway and the emissions of CO₂ and NO_x related to all three means of transportation. Also for the conversion between the different forms of energy, all standard conversion factors were used. To provide a comprehensive and comparable analysis of all three delivery chains, the three alternatives were modeled using the event driven process chain concept (EPC).

The transport distances showed no large difference between direct truck transport and ship but shorter distances for rail transport.

The results of the cost analysis show that, under the given circumstances, the costs of direct truck transport and of transport by ship are nearly equivalent. The cheaper, main transport phase by ship is partly outweighed by long and expensive pre-transport to the harbor. Transport by train was cheaper. This was mainly due to the fact that the pre-transport distance and cost, from the forest to the train station, was lower.

Regarding the specific energy consumption, railway and ship are by far more energy efficient than truck transport.

The CO₂-emissions follow the pattern of primary energy consumption. Truck transport has nearly double the CO₂-emissions compared to ship and railway.

The relatively high CO₂-emissions from railway transport is due to the fact that the electricity mix for railway transport includes a substantial part of electricity produced by brown coal. In other countries or regions, where the electricity is produced primarily with e.g. hydro power, the railway may benefit from this fact. An additional reason is the dependence on diesel engines on the secondary lines of the rail network that are characteristic to rail roundwood transportation

The picture is different regarding the NO_x emissions. Ship and truck are both fuelled by diesel and therefore have a clear disadvantage compared to the railway with the largest share being electric traction.

The results show clearly, that the cost advantages and environmental benefits of ship and railway transport phases, are partly outweighed by the necessity of pre-carriage - the roundwood has to be transported from the forest to the nearest harbor / railway station by truck - and that even big mills do not always have direct access to fluvial / railway lines, which makes post-carriage necessary - again by truck. Loading between the different means of transport also causes higher lead times and additional costs.

A consequence would be, that the (dense) railway network in Central Europe, and especially in Germany should provide more stations which allow the loading of roundwood on the railway. Sawmills and other wood industries should be connected directly to railway and/or should have close fluvial access to be able to make full use of the cost benefits and the environmental advantage of long distance transport by alternative transport means (ship and railway).

In the case study, bottlenecks at the loading stations (railway loading stations and harbors) were quite common during the “hot” phase of the windfall logging campaign. Consequently, the pre-transport distance was not always optimal. An alternative calculation using the optimal distances from the respective forest location to the next harbor / railway station resulted in a substantial decrease of the pre-chain distances. This shows that a very careful logistic planning of the wood flow can contribute to lower transport distances and the related cost and environmental impacts, especially in the case of catastrophic events.

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Efficiency of wood procurement systems of small-diameter Scots pine based on the wood paying capability of a kraft pulp mill

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Introduction

Integration of energy from wood harvesting into that of pulpwood is considered a means for reducing procurement costs of small-diameter wood. In the whole-tree systems, all biomass components above the stump cross-section are harvested. Specific separation facilities are not needed when pulp and energy fractions are separated in the debarking drum of the pulp mill. Transportation costs of un-delimbed trees can be reduced by compacting them into bundles by the newly-developed Fixteri bundle harvester.

The amount of biomass harvested per unit of area affects harvesting costs, and composition of whole-tree material differs from conventional pulpwood. Our study was aimed at evaluating the efficiency of three supply systems of Scots pine (*Pinus sylvestris* L.), considering the effects of raw material yield and its composition on wood procurement costs and on the economy of pulp making.

Material and methods

The supply systems included in the comparison were as follows:

- 1) Conventional cut-to-length (CTL) harvesting with a medium-sized single-grip harvester, forwarding with a forwarder, and road transportation with a standard timber truck and trailer.
- 2) Whole-tree cutting with a harvester equipped with multi-tree handling accessories, forwarding with a forwarder, and road transportation with a truck and trailer equipped with solid side panels and bottom.
- 3) Multi-tree cutting and compaction of whole trees using a bundle harvester, forwarding with a forwarder, and road transportation with a standard timber truck and trailer.

Relative wood paying capability (WPC) of pulp mill capable of selling excessive energy into the market was used as the criterion for the efficiency. WPC is considered a residual value that the forest product or the industrial process can “pay” after all costs (excl. wood) have been reduced from the sales prices. In the sensitivity analyses, the effects of pulp and energy (electricity and heat) prices, as well as terrain and road transportation distances were examined. In the basic calculation, the following price parameters were used: pulp 500 €/ADt, electricity 50 €/MWh, and heat 10 €/MWh.

Relative residual values were computed for wood harvested from three thinning stands with breast-height diameter of the removal of 6–12 cm. Recovery and its composition were assumed equal in the whole-tree options. When constructing raw material balances of wood handling, these assortments were assumed to be debarked and chipped as blends with conventional pulpwood, in order to minimize wood losses. The methodology applied in our study is described in detail in Jylhä et al. (2010).

Results

When compared to CTL harvesting, whole-tree harvesting increased removal by 169%, 58%, and 16% in Stands 1–3, respectively (Fig. 1). In Stand 1 with the smallest trees, additional raw material originated mostly from under-sized stems. Branches constituted 9–20% of the removal. The harvesting of loose whole trees resulted into the lowest procurement costs in the cases of Stands 1 and 2, while CTL harvesting was the most cost-efficient option in Stand 3. The forwarding costs of whole-trees were reduced by 44–60% and road transportation costs by 43–48 % with whole-tree bundling, but these savings were insufficient to balance the costs of compaction.

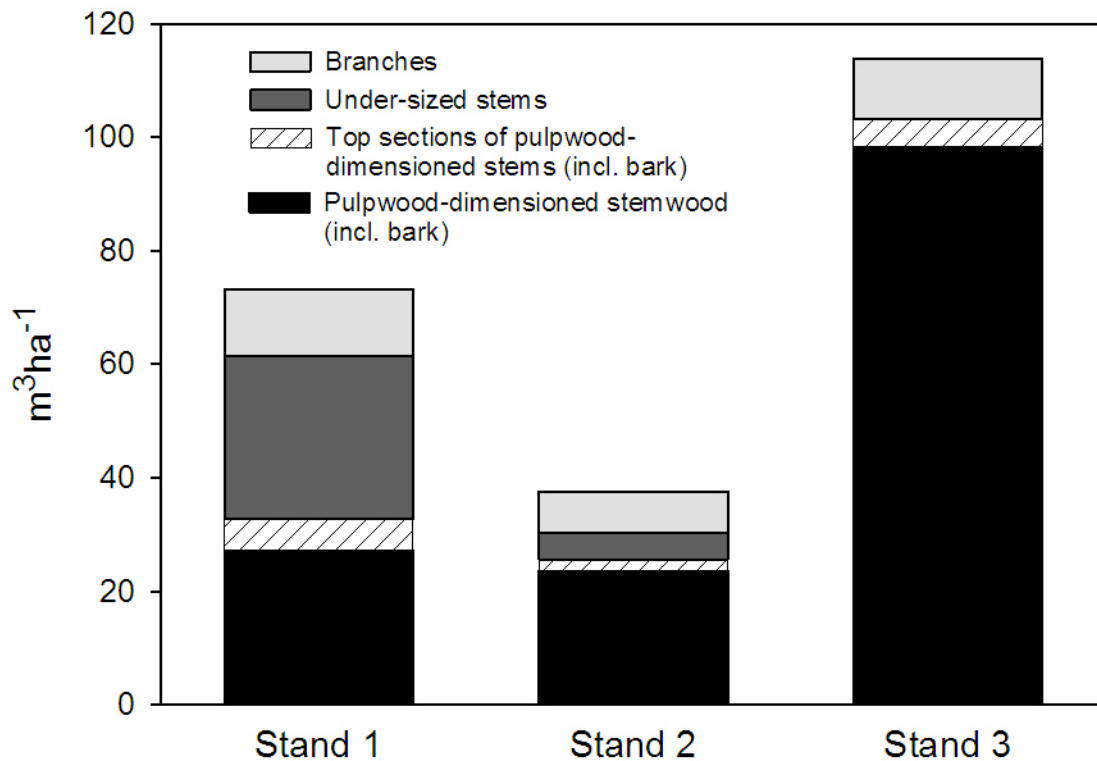


Figure 1. Removal and its composition on the case stands. Mean breast height diameters in Stands 1–3 were 6, 8, and 12 cm, respectively.

Pulp price had the strongest effect on the WPCs per m^3 at the pulp mill (Fig. 2). Conventional pulpwood had the highest residual value in all stands. Its residual value remained the highest at stump in most cases within the pulp and energy price ranges applied in the sensitivity analysis (350–650 €/ADt and 30–70 €/MWh). However, loose whole-trees gave the highest WPC in Stand 1, when pulp price was less than 427 €/ADt. When removal per hectare was considered, loose whole trees had the highest residual value in Stands 1 and 2, except for with extremely low pulp prices (< 359–374 €/ADt). The proportion of additional raw material was lowest in Stand 3 with the largest trees. There CTL harvesting resulted in the highest residual values within the examined price ranges also on a real basis.

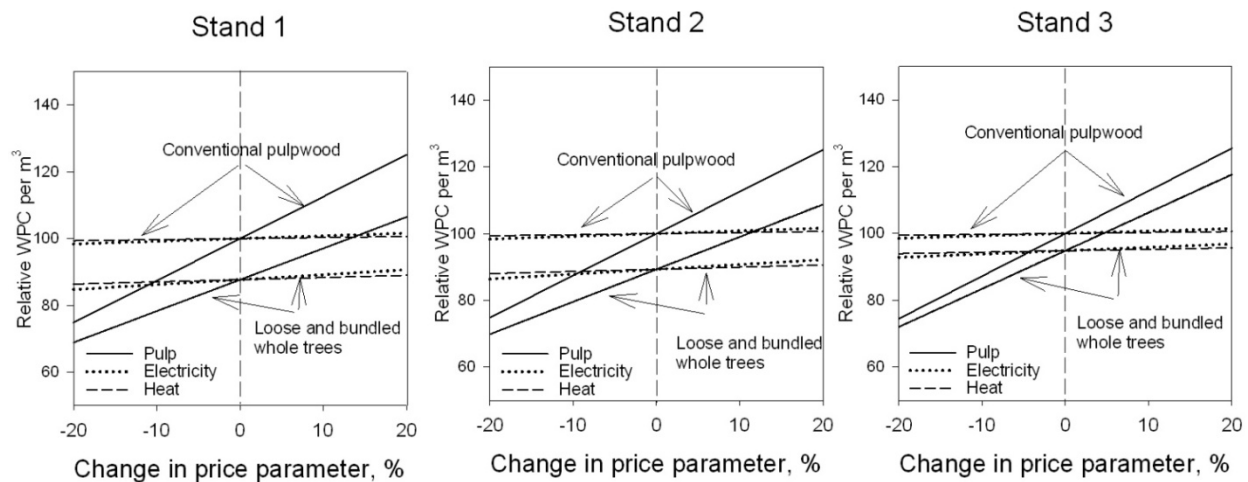


Figure 2. The effect of price parameters on relative WPC per m³ at mill by stand and by supply system.

Within the forwarding distance range of 50–1000 m, conventional pulpwood had the highest and bundled whole trees the lowest residual value per m³. When the increase in removal was considered, loose whole trees had the highest residual value throughout the range in Stand 1. In Stand 2, loose whole trees had the highest residual value up to 780 m. In Stand 3, conventional pulpwood gave the highest WPC on a real basis as well. The WPC with whole-tree bundles was lower than that with loose whole-trees in all cases.

In Stand 1, loose whole trees had the highest residual value, when road transportation distance was less than 30 km. In the other stands, conventional pulpwood gave the highest WPC per m³ throughout the examined range of 5–500 km. When removal per hectare was considered, loose whole trees had the highest residual value when truck transportation distance was less than 70–250 km. Whole-tree bundling was a competitive alternative to the harvesting of loose whole trees in Stands 2 and 3 when road transportation distance was more than 440–450 m. In Stand 1, whole-tree bundling was the least competitive alternative in all cases.

Discussion and conclusions

Our study showed that harvesting factors have by far more significant effect on the WPC than raw material properties within first-thinning stands. Decrease in pulp price and increases in energy price improve the competitiveness of the whole-tree options, but the increase in energy production does not compensate the losses in pulp production. Taking increase in removal into account improves the competitiveness of the whole-tree options drastically, especially when lower stumpage price of whole-tree material is considered.

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Using network analysis in configuring appropriate biomass supply systems

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As presented at the Fourth Forest Engineering Conference.

The use of swap bodies for skidding and roundwood transportation

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As presented at the Fourth Forest Engineering Conference.

Challenges and adaptation opportunities in changing business environment

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The economic recession has changed harvesting business with mill closures, long harvesting standstills and new customer policies. The objectives of this study are to ascertain development of Nordic wood harvesting business and to bring problems into discussion. Data on all registered harvesters and forwarders in the Finnish Transport Safety Agency database were collected. A list of machine owners was entered in Statistics Finland Closing of the books databank. There was about 1 000 enterprises with full closing of the books data 2001 – 2008. Materials were analyzed using statistical and balance sheet analysis.

During 2001-2009 the average commercial roundwood removals in Finland were 52 mill. m³ per annum. In 2007 the record of 58 mill. m³ was reached, but just after that the long time bottom 42 mill. m³ was reached in 2009. Many mills were closed and the forest industry halted harvesting operations for months. During the recession, the forest industry restructured their wood procurement organization. The three biggest integrated industry companies, which are responsible for 80% of total harvested volume, decided to favor larger harvesting enterprises in the future and thus outsourced where new agreements are based on competitive bidding.

New situations require restructuring of the small enterprise intensive business. These are businesses that have been through times moderately or poorly profitable (Mäkinen 1993, Väkevä & Imponen 2001). During the period 2001-2008, smaller harvesting enterprises had lower profits than larger enterprises (fig. 1). On the other hand, the variation of profits, illustrated by lower and upper quartiles, is widest for the smallest enterprises. Only one quarter of large enterprises have negative results, but there is also no high results rewarding entrepreneurship.

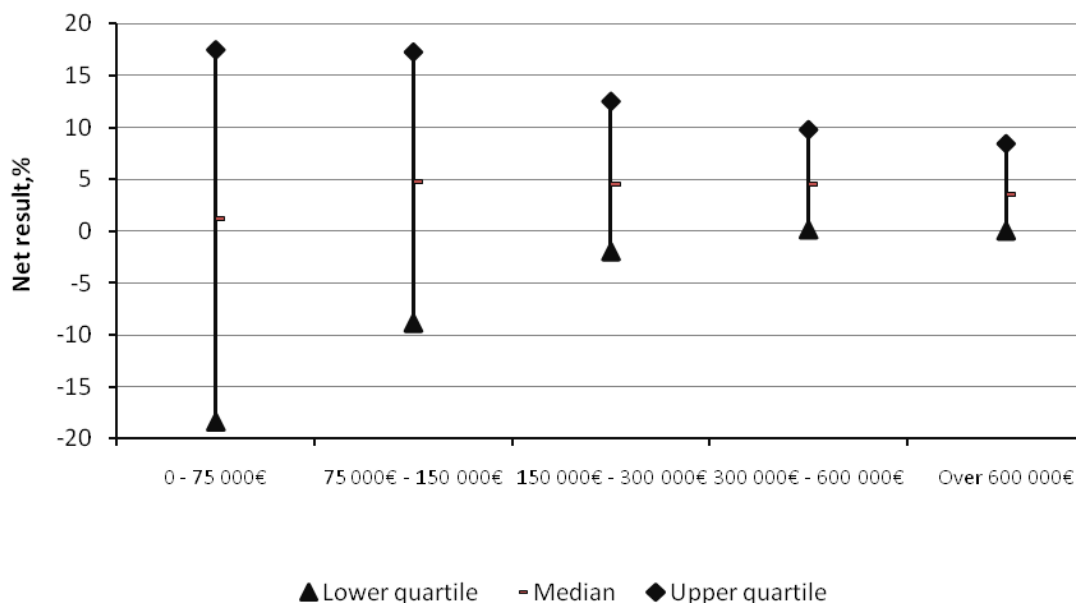


Figure 1. Median and lower and upper quartile of net profits in 2008 by enterprise turnover size. Data from Statistics Finland (2009).

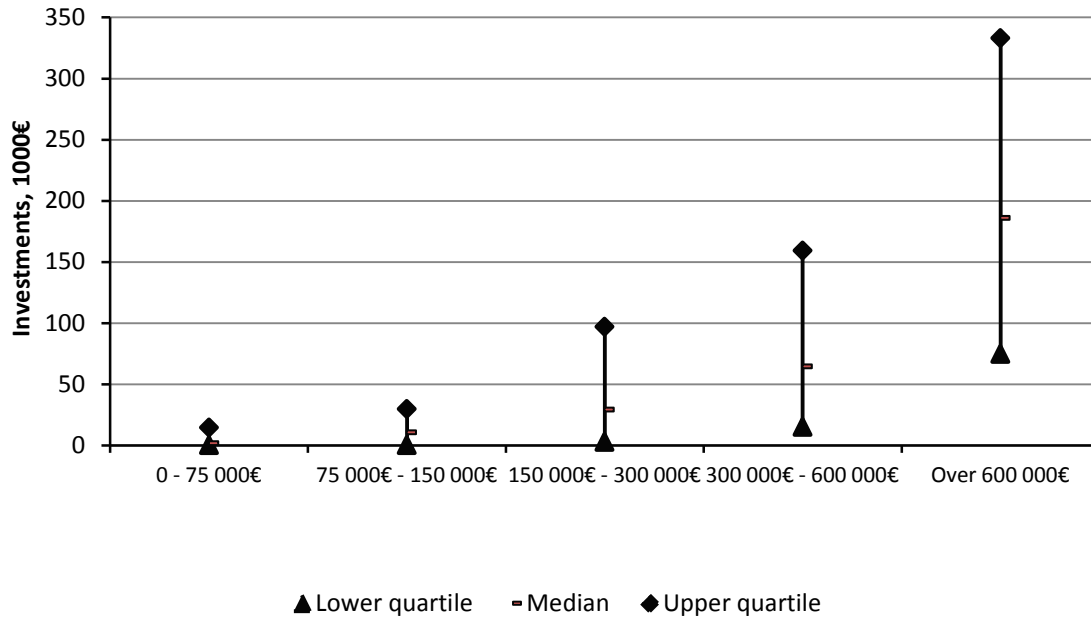


Figure 2. Median and lower and upper quartile of investments in 2008 by enterprise turnover size. Data from Statistics Finland (2009).

Low profits make it difficult to grow the enterprises required to fulfill the requirements of large customers. Only the largest enterprise class has invested yearly, with a sum which equals the value of a second hand forwarder (fig. 2). Economic reserves, which can be used for symbolizing organic growth of an enterprise, are worth only the down payment of a new forwarder in the largest enterprise class. In smaller classes, it is almost zero.

When following the growth development of the enterprise class (measured by turnover) movements, one can see that the share of enterprises with turnover over 600 000 € per year has grown from 13 to 23% during eight years (fig. 3). Part of this development stems from growth of enterprises and part is the result of smaller enterprises disappearing. The share of medium size enterprises has not changed much. Nevertheless, the growth stopped after the record harvesting year 2007. It is a question of how radically the growth has started again after that, when customers have required larger enterprises.

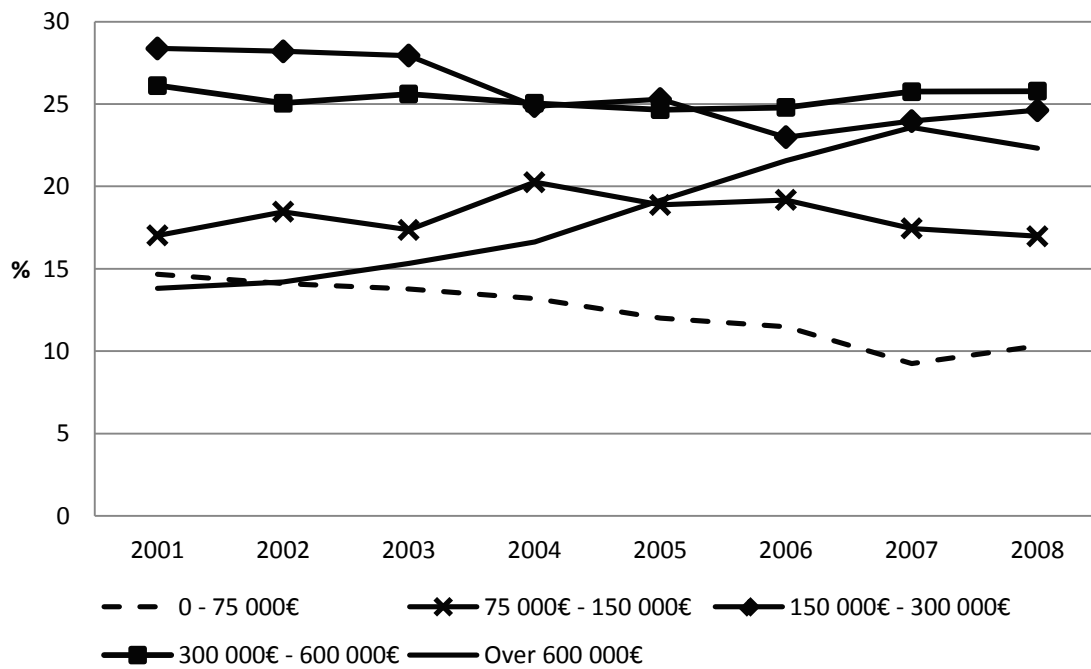


Figure 3. Development of share of enterprises in 2008 by enterprise turnover size. Figure contain only enterprises which were operating in 2007. Data from Statistics Finland (2009).

The low or negative profits make it difficult to hire competent operators and to encourage new generations to become entrepreneurs. Earlier entrepreneurs were good at both work and keeping machines in order. Now, with bigger enterprises owners, should also be leaders and economists. Forty per cent of costs in forest machine enterprise are wages and other personnel costs (fig. 4). In most cases, operators are paid by the hour and their travel expenses. The work productivity, quality of remaining site and thus also profitability of business depends very much on the abilities of the operator.

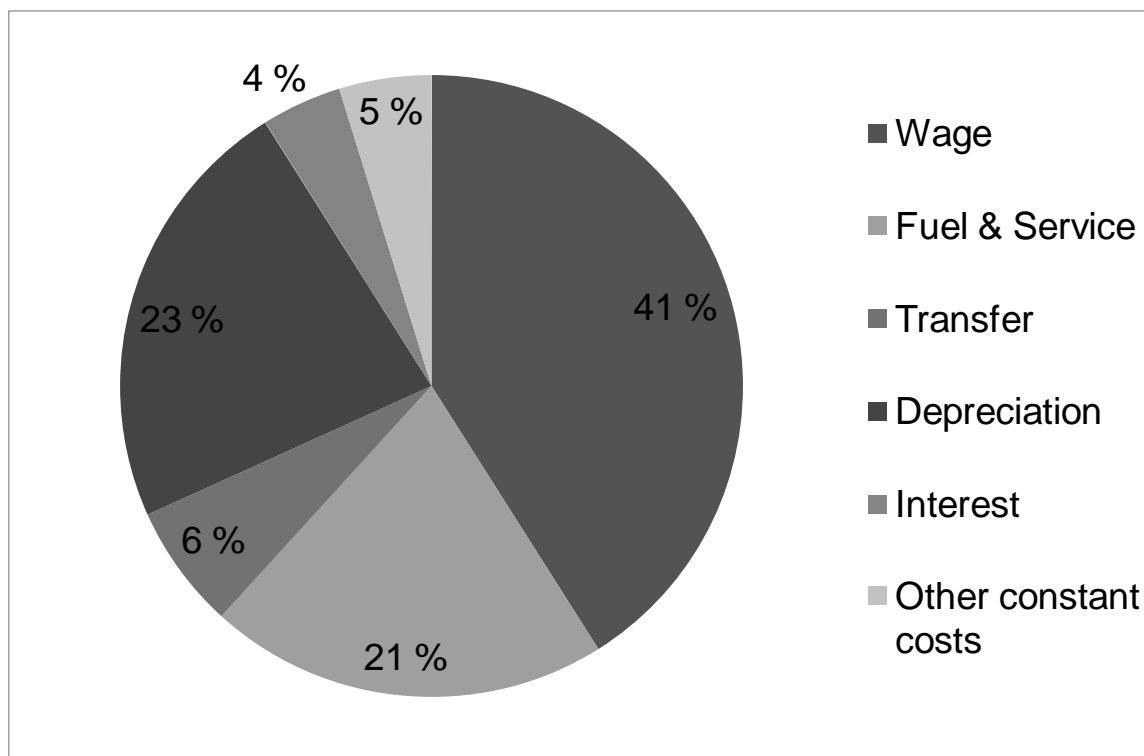


Figure 4. Cost structure of forest machine enterprises in 2009 (Cost index ... 2010).

The seasonal variation of logging volumes in Finland is high. Partly this is due to traditions and partly because snow and frozen soil increases logging in winter time. In January, harvesting volume is over 6 mill. m³ compared to 2.5 mill. m³ in July (Metinfo 2010). How is best to deal with this capacity variation? Standing machines still have capital expenses for which there is no compensation.

There is need for rethinking in harvesting business. There should be more real discussion between customers and entrepreneurs. Company specific technical solutions, e.g. scaling and data transfer systems often lock entrepreneurs to one customer. All big customers, except Metsähallitus (State Forest), transfer all their capacity risks completely to entrepreneurs. Even wood market transactions include some factors which complicate optimal wood harvesting. Common negotiations between all parties could create better possibilities for optimal work and mutual profitability.

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Forest Biomass Supply Chains - there is more to it than one might think

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Increasing cost effectiveness and thus lowering cost of forest fuel procurement is a key issue in the research of forest fuel supply chains given that there is a substantial gap between technically harvestable and economically available forest fuel potential. In order to address this challenge, an in-depth holistic approach is required. To optimize existing supply chains and to design new, innovative ones, all processes and interactions of the supply chain must be taken into account.

The presented study investigated 3 supply chains in different operational environments (Finland, Germany, and Scotland) by using methodologies and tools commonly used in modern business management but that have not found their way into the research of the forest energy business. The objective was to map and investigate the relationships, communication and data exchange among the different stakeholders. Furthermore the time consumption of organizational and managerial tasks was estimated by using discrete-event simulation based on the process maps.

The business process mapping revealed that the number of processes in the supply chains varies considerably depending on the different operational environments. While the Scottish supply chain involves only 101 processes, the ones in Finland and Germany, involve 213 and 268, respectively. The work time expenditure on managerial and organizational tasks is only 627 minutes in Scotland, but the Finnish and the German supply chain involve 1276 and 2060 minutes, respectively.

Even though the results of the study are company specific and cannot be generalized, each supply chain reflects unique characteristics of its operational environment. The methodology used has proven its potential for the analysis of supply chains in forest business and is a step towards holistic cost calculation and optimization approaches on a supply chain level.

Simulation studies of in-stand chipping for minimizing storage and relocation costs

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As presented at the Fourth Forest Engineering Conference.

Medium term ICT deployment strategy in the French wood-supply chain: collective challenges, experiences and forthcoming actions.

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Abstract:

French marketed wood harvest is about 36 million cubic meters per year. This volume is handled by 12,000 companies from wood suppliers, harvest companies, transportation companies to primary processing industry. The forest-based sector is very heterogeneous whenever it comes to forest resource (wood species, mechanization), type of companies (size, products & market, information systems), and regional practices (selling procedures, cooperation habits between stakeholders). In a demanding context where economics must be balanced with social and environmental expectations, this heterogeneity is a critical limit for the sector's efficiency.

New tools are needed to help French forest-based SMEs becoming more flexible, reactive and able to anticipate their activities. Demonstrations from other industrial sectors highlight that ICT means are relevant to support such gain of competitiveness.

For several years and with the constant cooperation of its professional partners, FCBA has been involved in the field of IT & logistics, both on the operational side (RTD and demo projects) and on the standardization side (Forest Wood Supply group of papiNet). Thanks to this experience, the most strategic axes to be developed were identified. Within the next five years our objective is to offer to wood supply companies new means to manage their activities on a strategic and tactical level. These tools will rely on simulations and models, based on real time data collected from the different supply chain steps as follows: resource evaluation, logging, logistics and primary processing.

In this perspective, the challenge is to develop (i) standardized data exchange between the different processes of a company as well as between companies; (ii) traceability; (iii) prediction models; (iv) management tools as well as (v) optimization tools and decision support.

Because technical constraints are often only the tip of the iceberg, adoption must also be considered as well as the search for innovative schemes both from the economic point of view and the governance of the deployed infrastructure.

This ambitious program has already begun through a collective project dedicated to the development and deployment of an infrastructure of services. éMOBOIS first focuses on standardized data exchanges. Two pilot actions involving 20 companies will test, on one hand, the automatic exchange of 3 standardized eDocuments (Measuring Ticket, Harvesting Production, Delivery Instruction) and on the other hand, for companies without information system, the use of a web service to read and to send eDocuments.

Interoperability will be ensured so that services developed later on will be easily connected to the infrastructure and thus easily accessible by users.

A second action consists in implementing wood traceability from the forest to the mill in order to optimize the use of raw material. This requires the development of models (models for resource characterization of the resource and to identify optimal uses) which compile real time data exchanged thanks to the éMOBOIS infrastructure.

Concurrently, FCBA aims at improving cooperation between performers. One critical milestone to reach this challenge is to demonstrate that added-value created by cooperation and based on Information Technology, will be shared between the different performers involved in the supply chain. The chosen approach is to start with a group of leaders and steer broader adoption by propagating the demonstrated success stories to the other actors.

On the horizon of 5 years, we do not claim that we will revolutionize the wood supply chain in France. However, we wish to trigger a strategic approach where stakeholders would think globally and act locally. With relevant success stories and indicators, proof can be made that two major opportunities are within the reach of forest-based SME:

- Better use of wood as a raw material thanks to more accurate prediction of the quality of forest resources
- Cost reduction enforced by cooperation between stakeholders.

Keywords: Competitiveness, ICT deployment in the supply chain, standardized data exchange, traceability, Optimization, Adoption.

Integrating market, environmental and customer information in value creation: the case of forest operations in a tropical country.

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Present day high cost of production in the forest industry sector and the market desire of firms to ensure customer satisfaction in regards to multidimensional definition of product quality have increased the need for global value chain efficiency. Competing efforts are being made by firms to improve their supply chain processes in order to capture the customer base. This has strengthened existing competition and the need for continuous improvement of production processes. The new partnership for Africa development (NEPAD), for example, recognized the need to place countries on the path of sustained economic growth and sustainable development at the 2002 world summit in Johannesburg by improving industrial performance inter alia. Unfortunately, although most forest industries in the continent are large, based on the EU employment classification of industries, they are incompatible with their European and North American counterparts when profits and market access are concerned. In Cameroon, where this study is applied, 70% of logged wood is transformed locally yet, added value on products and services remains below expectation. The net contribution of forest operations to the country's economic wellbeing is therefore under great scrutiny especially when considering the potential environmental impacts.

The advent of globalization has granted more forest goods and services easy access into the global market. As such, the need of firms to meet consumer expectations and environmental responsibilities in order to stay in business has become a necessity. Furthermore, the use of the right and timely information within different processes can generate value creation opportunities for forest-based value networks. Integrating customer, market and environmental information related to forest operations along a value chain will therefore be critical for increased agility, optimal customer satisfaction and sustained competitive advantage of firms. The thrust of this submission is however that forest industries are unaware of how they should integrate these components into their value chains in order to fine-tune forest operations.

This paper uses the SCOR modeling framework to develop a generic model for forest value chain efficiency. It explores a first attempt at incorporating innovative mechanisms like carbon information into the value creation network of forest industries. The paper also offers local entrepreneurs the possibility of establishing effective and agile value creation networks. A description of value created and the various points of creation with respect to receiving, creating and processing of information within heterogeneous processes along the entire chain are reported.

Research strategy for the study is built on hypotheses derived from theoretical constructs of the value chain concept. Three key elements (market, environmental and customer information) are used to discuss the importance of information management on the operational performance of a value chain. A hypothetical comparison of industries with respect to information management methods is illustrated. The paper lays particular emphasis on the relevance of the SCOR-Model which though considered as one of the more rigorous and comprehensive models for understanding a supply chain still has few applications in the field of natural resources management. It also focuses on value capture through the development and value stream mapping of an information-based threaded-diagram on carbon, market and customer-tailored

aspects. The study is based on forest operations in Cameroon, but the generic approach that is proposed can be adapted in other contexts.

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An application of data envelopment analysis for the lumber industry in northwestern Ontario

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Extended Abstract

Canada has about 402 million ha of forest land that accounts for about 10% of global forests and 30% of boreal forests in the world. The forest sector has been the mainstay of northwestern Ontario's (NWO) economy in Canada as it generates a significant amount of direct and indirect employment in this region. However, the forest industry in NWO has come under significant competitive pressure in recent years both due to declining productivity and increasing global competition, resulting in numerous mill closures. Maintaining economic and employment benefits from the forest sector; therefore, requires an in-depth analysis of the relative technical efficiency of individual mills. The relative technical efficiency of a mill, with disproportionate inputs and output combinations, measures how efficiently the inputs are being utilized in the mill to achieve the desired output in comparison to its peer group. There are no studies that analyze the forest products industry's relative technical efficiency at the mill level in NWO. This study aims at exploring the technical efficiency in the lumber industry using data envelopment analysis (DEA). The DEA model analyzes relative technical efficiency of lumber mills with disproportionate inputs and outputs for two periods by dividing the 10-year time series data, for inputs and outputs of 24 lumber mills, over two periods (1999-2003 and 2004-2008). We use four inputs, namely, material (log volume), labor (man-hours), two types of energy (hog-fuel and electricity), and one output (lumber volume) in this study.

Our trend analysis finds an annual reduction of 10%, 13% and 13% for lumber output, log consumption (input) and number of employees, respectively, during the period 1999-2008. That means the lumber production in 2008 was only 39%, and log consumption and number of employees only 29% of their respective values in 1999. This indicates a critical situation for the lumber industry in NWO, where the main economic activities have been supported by this industry for decades. However, we did find that log consumption increased by 33.7% and employment by 1.4% in the value-added (other than primary) forest products industries during the same period. Therefore, there is a growing consensus among the forest sector stakeholders that there should be more focus on the value-added industry in order to boost the forest sector economy in the region.

The results from DEA with two scenarios *with energy inputs* and *without energy inputs*, for the two periods are found to be mixed and interesting (Table 1). While some mills have improved their performance in terms of best use of available scarce inputs in the second period, some have shown negative per cent change in efficiency. The interesting results for Mills 12 and 15 (mill codes are used to hide mill identity) are that they both had zero per cent change in both the scenarios; indicating that the mills are using their resource most efficiently in both periods under both scenarios relative to their peers. In the *with energy input* scenario, most of the mills show a reduction in efficiency with the highest estimated reductions (-13.9%) for Mill 1 and Mill 21. However, in the *without energy input* scenario, the highest reduction is for Mill 16 (-47.6%) followed by Mill 21 (-33.1%). A possible explanation for these negative performances of mills is the decline in production in the second period compared to the first period, where these mills were not able to adjust their inputs (mostly labor) as proportional lay-offs might not have been

possible. This means these mills were running with more man-power relative to their production levels. Some mills improved their efficiency in the second period mostly in the *without energy input* scenario. The highest improvement (107.8%) is found to be for Mill 6 followed by Mill 18, Mill 14, Mill 9, Mill 2 and Mill 3. These mills were able to improve their technical efficiency by adjusting their inputs over time, learning from previous production trends relative to their peers.

These results suggest a proportionate adjustment of inputs in the lumber mills of NWO to efficiently achieve the desired outputs. Given the accuracy of input data used in this study, we conclude that the model results *without energy inputs* in both the periods are more policy relevant. The model results with all four inputs are also important to observe the sensitivities of efficiency scores and weights, when some inputs are less varied than others. The results give more weight to the lower value inputs, and the variation in efficiency score is offset by lesser variation in some of the inputs (electricity and wood fuel in our study). These results provide policy makers and industry stakeholders with an improved understanding of the trends of efficiency and employment as well as reallocation opportunities of future inputs in order to increase benefits from this sector.

Table 1: Change in relative technical efficiency of mills in NWO from 1999 to 2008

Mill codes	% efficiency change in two periods	
	With Energy	Without Energy
Mill1	-13.9	-14.5
Mill2	-7.2	22.8
Mill3	-7.9	20.7
Mill4	-3.8	14.0
Mill5	0.0	-2.2
Mill6	-9.2	107.8
Mill7	0.0	6.4
Mill8	-0.5	-13.7
Mill9	-4.3	26.1
Mill10	1.4	9.9
Mill12	0.0	0.0
Mill13	-5.8	-17.6
Mill14	0.6	28.7
Mill15	0.0	0.0
Mill16	-12.5	-47.6
Mill17	-4.3	1.2
Mill18	-5.9	74.8
Mill19	0.2	3.0
Mill20	0.0	1.4
Mill21	-13.9	-33.1
Mill22	-2.2	27.2
Mill23	1.5	-21.4
Mill24	1.5	-3.8

% efficiency change estimate for Mill 11 is not reported because of missing data for this mill in the second period

Logging contractors in forest owners associations - Applying TPL theory on the management of business relationships

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This paper aims to identify, present and discuss relevant theories for tailoring service-buyer and -provider relationships concerning logging operations in the segment of Swedish forestry operated by forest owners associations (FOAs). The paper presents a review of Swedish logging services, with focus in FOAs. In addition, relevant theories applicable to the management of business relationships have been searched in international scientific journals. The paper is written as an introduction to a PhD project within the Swedish-Finnish Forest Industrial School on Technology (FIRST).

For more than half a century, the productivity in logging operations has continuously increased. Since a few years ago there have been indications of a declining productivity (Nordfjell et al. 2010). In the later years, the complexity of logging operations has also increased. Furthermore, the demands on quality and precision have increased (Högnäs 2000), as well as environmental and social demands (Hultåker 2006). Sophisticated computer technology is now used to support the planning and control of these operations (Högnäs 2000).

Adding to the complexity, the Swedish forest industry acts on an international market, with high demands of productivity enhancement in order to stay competitive (cf NRA-rådet 2006). One of the applied strategies to deal with productivity and cost reduction has been to outsource logging services. Today, most of the logging operations are performed by contractors owning their own equipment (Norin & Furness-Lindén 2008). Most of the financial risk for the capital-intensive investments in machinery stays with the contractors. In order to retain willingness for continuous development, suitable business concepts have to be applied by the service-buyers that stimulate both the desired development and allow contractors to have long-term profitability and reduce investment risks (Norin & Furness-Lindén 2008, Norin 2000). A problem since the middle of the 1990s is that profitability in the logging sector has been low (Hultåker, 2006). At the same time, the sector also has problems in recruiting and retaining competent operators due to the perceptions of a stressful work environment and low salaries (Bergquist 2009). Long-term profitability is necessary to keep the sector attractive and secure a continuous inflow of competent contractors. Alliances in the form of partnerships –with long-term cooperation- may be a way to increase both the effectiveness and the profitability (Marasco 2008, Skjoett-Larsen et al. 2006, Norin 2002, Högnäs 2000).

Swedish forest owners associations (FOAs) have some special characteristics, making them interesting for case studies in this respect. Historically, their function was as middlemen for their self-active members, purchasing many small volumes of roundwood and selling large volumes to the industry (Berlin 2006). As self-activity has decreased, the FOAs have developed into full-scale forestry service companies offering both silviculture and logging services to their members and also to other non-associated forest owners from whom they buy timber and/or offer services to (cf www.sodra.com). As service-providers, there are many demands on the contractors –not only on the quality and precision required by the industry, but in this case also on keeping a satisfactory service-level towards the forest owners. Meanwhile, there are continuous changes in market conditions, causing uncertainty and variations in work-volumes. This is probably largely

influencing the business relationships between an FOA and its associated contractors. Efficient management of mutually beneficial partnership alliances under these conditions requires a well-defined interface and a clear governance structure.

Third-party logistics (TPL) gives us extensive theory for modeling and managing partnership relations. The definitions of TPL vary widely (Marasco 2008, Skjoett-Larsen 2006), but it is basically about a mutually beneficial relationship between two parties, where a customized logistic solution is worked out in cooperation. It is a relationship linking seller, buyer and logistics service provider in a supply chain. More specific for the Nordic countries, TPL relationships are of an integrative nature and are characterized by long-term contracts, customized or joint logistics solutions and a win-win relationship that is based on trust (Skjoett-Larsen 2006).

The most extensive review found on TPL research has been presented by Marasco (2008). She has made a content analysis of 152 scientific articles written about TPL during 1989-2006, and offers a content classification scheme of all these articles. Using this as a platform, the intention is to use TPL research as a theoretic toolbox in the PhD project when analyzing possibilities to improve and tailor relationships between a forest owners association and its associated logging contractors with the aim to increase effectiveness.

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Prehas-software for pre-harvest assessment of timber assortments

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Background

Pre-harvest information of growing stock is needed for adjusting timber purchasing, pricing, stand allocation, bucking objectives and timing of forest operations to meet the needs of production. The information should include the volumes, log length-diameter distributions and qualities of sought timber assortments. For this bucking simulator fed by stem specific prediction including technical quality is essential.

For the required stem specific information of stand properties timber assortment recovery regression models (e.g. Nyyssönen & Ojansuu 1982) have been developed. However, these models have not considered the technical defects of the stem affecting the assortment recovery. Recently developed methods based on the use of airborne laser scanning (e.g. Peuhkurinen et al. 2007, Korhonen et al. 2008) offers interesting prospects, although methodology for species specific prediction of timber assortment recovery demands more detailed data than usually is available. Timber assortment predictions based on stem database and bucking simulations (e.g. Deadman and Goulding 1979, Malinen 2003) offer more precise predictions than assortment recovery models. However, these methods require quite a detailed stem description and bucking simulators, which are seldom available.

In the Finnish Forest Research Institute, software capable of predicting harvested volumes, timber assortment recoveries, length-diameter distribution of logs and value recovery was developed. The software utilizes harvester collected stem database which can be updated with local data by the user. The software has three versions, Prehas-International (figure 1), and two country specific versions, Prehas-Scotland for Scotland and ARVO for Finland.

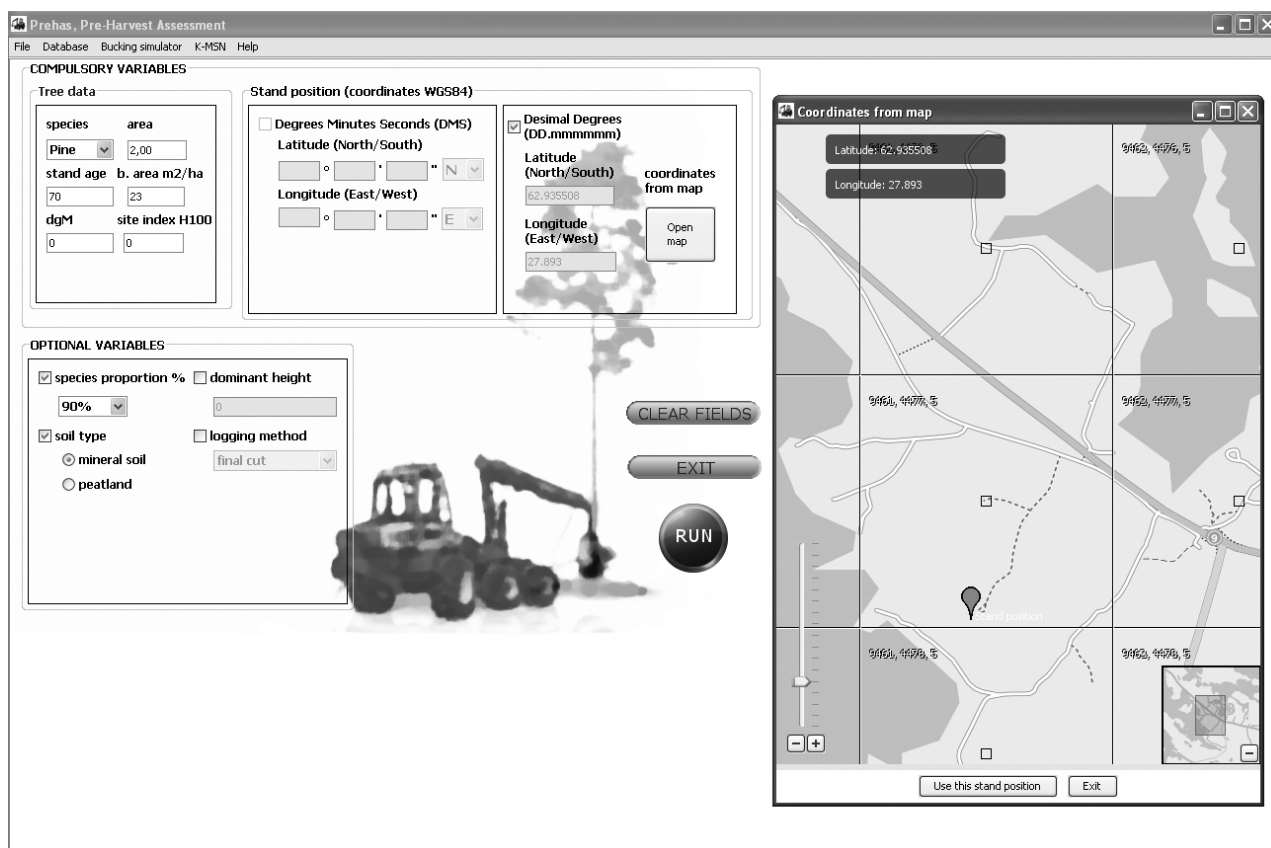


Figure 1. The user interface of Prehas-International.

Materials

While harvesting, modern harvesters continuously measure the diameter of the stem. From these measurements, the harvester saves diameters by ten centimeter intervals to a stm-file (StanForD 2007). By using this detailed data along with stand variables describing site conditions, it is possible to build a stem database which can be used to predict timber assortment recoveries of growing stock.

The predictions of Prehas are based on this stem data (stm-data) database, which is stored into software. In addition to this, Finnish version ARVO includes stem quality data containing over 13 000 stems measured for the dimensions and assessed for the stem quality, with particular attention to estimating visually the occurrence and measuring the effective lengths of the technical defects, such as sweeps, crooks, branchiness and scars. This data is used to predict technical quality affecting on the bucking of the stems predicted from the stm-data. Due to lack of similar data from other countries, this feature has been replaced in the Prehas-International and Prehas-Scotland with feature where the user is able to input any data, define what variables are under interest and what variables are meant to be used as predictor variables. However, it is not possible to utilize these predictions in bucking of stems.

Due to regional variability in growing conditions, stem dimensions and quality, it is impossible to offer a stem database useful for everywhere. Thus, the purpose is that each user collects their own local database by utilizing Prehas routines to save stm-data in to stem database (figure 2). Collecting stm-data is easy and fast for everyone who has access to harvesters' data systems.

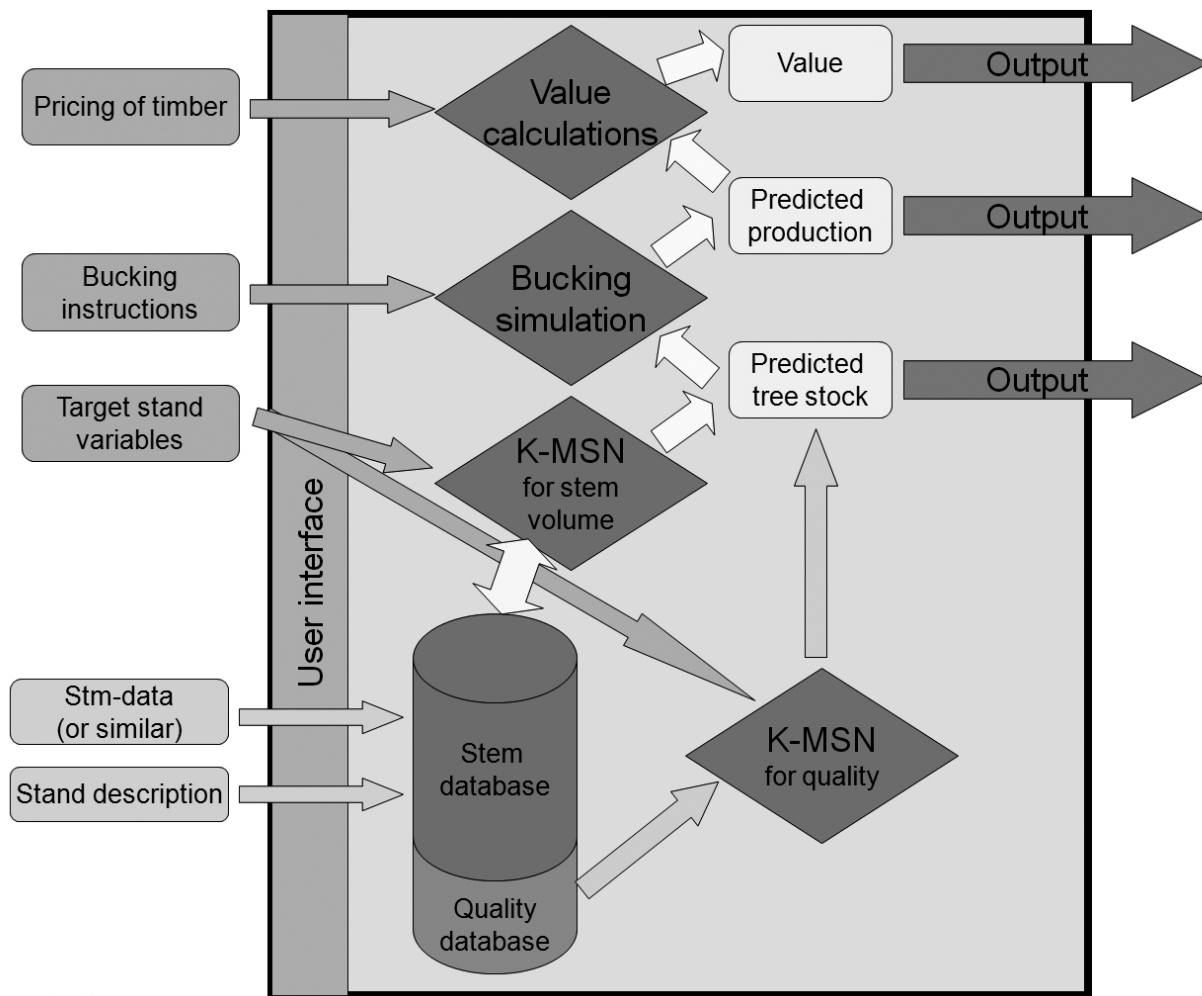


Figure 2. The main functions of Prehas software.

Non-parametric methodology

Prehas utilizes so called non-parametric methodology in the making of predictions of stem stock. Non-parametric methods predict the value of the variable of interest as the weighted average of the values of neighboring observations with neighbors being defined by the predicting variables (e.g. Härdle 1989, Altman 1992). These methods are characterized as flexible and powerful in estimation of values (Altman 1992).

The distance function defines the neighborhood, i.e. how the measured observations are located in the surroundings of the target of the prediction. The method used in the Prehas is the K-MSN method, which is a special case of a general k-nearest-neighbor method. The calculation of the similarity is based on canonical correlation analysis and Mahalanobis (1936) distance function (Moeur and Stage 1995).

The main advantage of the MSN distance is the fast computational method to produce weights for distance metric with a multivariate approach. This enables updated weighting for independent variables with continuously updating databases. In addition, it provides transformability of the application without extensive knowledge about the correlation structure of the data (Malinen, 2003).

Discussion and Conclusion

Since the idea behind non-parametric estimation is to associate previously collected information with target observation, the performance of these methods is greatly dependent on the data used. Modern harvesters are capable of collecting huge amounts of data without additional expense. The applicability of the software is therefore relying on the shoulders of potential users; you have to collect own data in order to get accurate predictions.

Prehas and ARVO software's are distributed free of charges at the Finnish Forest Research Institutes web site <http://www.metla.fi/metinfo/arvo/index-en.htm>. The development of Prehas –software has been funded in EU's Northern Periphery –programmes project Developing the Scots Pine Resource.

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LiDAR and hyperspectral remote sensing for the forestry industry

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Session 5

Technology Adaptation for Specific Environmental or Technical Demands

Chaired by: Jean-Francois Gingras & Bruce Talbot

Adjustment of forest harvesting procedures to different site conditions

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Fully mechanized harvesting methods are increasingly common for coniferous and smaller broadleaved trees throughout the world. Felling, pre-skidding, de-limbing and crosscutting are done using a harvester, while the transport to the forest road is the task of a forwarder (Fig. 1). Both machines drive on skid roads which are arranged in a parallel pattern 20 meters apart. This skid road arrangement minimizes the ergonomic strain and risks to the operators, and reduces harvesting costs, while damage to the forest stand is normally less than through other methods. However the machines are so heavy that the soil, on which they drive, can potentially lose its biological functionality and can later be used only for technical purposes.

In some cases this compaction of the soil can last for several decades; one could say that the soil has an extremely long memory. The following are the consequences of implementing a skid road system in timber harvesting.

1. Once a skid road - always skid a road. In order to limit the compacted soil during the next harvesting period, the previous skid roads have to be used again. From the very first planning period, skid roads have to be regarded as permanent infrastructure without any exception.
2. Skid roads lower the productive area in the forests. Normally, they do not influence the productivity per hectare because the canopy will close over the small skid road and the trees can obtain full light. The chance; however, for the silviculturist to promote the best stems in order to optimize the value of the stand is limited by the schematic opening up. This becomes increasingly important as the stand productivity increases. Here the silvicultural losses can cost more than the savings of mechanization. In this case, the distance between two skid roads should be enlarged to the double (40 m), or even the extreme high value of 60 m.

These two points influence the selection of potential harvesting methods, as a fully mechanized harvest method is not the optimal choice for every stand condition. The question remains though, which method is better for each situation? In Tharandt, a simple 5x5 matrix has been developed which is called the “technogram of soil”(Fig. 2):

- The x-axis is defined by the soil moisture which is classified in 5 steps from dry to extremely wet.
- The y-axis shows the productivity value of the soil, which corresponds to the distance between skid roads (no permanent skid roads, 20 m, 40 m, 60 m, and no machine access at all).

In this matrix, each forest site finds its “individual” field; however, this field can vary depending on two different influencing factors:

- Climate: If it is raining, the field moves one step to the right. If it has been very dry for several weeks, the field moves towards the left.
- Wood requirements: When the forest owner is interested only in raw mass production, than he can go down to shorter distances between the skid roads. If he sets the focus on high value and other soil functions, he tends to increase the distance.

This is the reason why the original field in the matrix can change with different influencing factors; but ultimately only one field characterizes the soil.

Subsequently, the forester has to decide which harvesting method will work best for a soil type. For this purpose, a second 5x5 matrix, which is called the “ecogram of harvesting method”, is constructed for each method. Here, in each field, the assessment can be seen, whether this method is optimal (star), good (plus), with some restrictions (minus) or not acceptable (black), (Fig. 3). In this way, an ecogram is developed for each possible harvesting method, allowing the decision maker to apply the tool in the following manner:

- First, he looks for alternatives which are optimal or at the very least good, under the given situation (= for the given field in the matrix). This serves the purpose of enlarging his view to the possibility of methods perhaps not previously considered.
- Secondly, he tries to forecast the consequences of each method. In doing so, he should consider more than the costs and productivity but also the damage, the ergonomic aspect and other “soft effects”. A full assessment of all alternatives should be done. In the event that a good alternative costs more than a poor one, this difference is an indication of the opportunity cost of the better method.
- Finally, he decides which alternative should be the best taking into account his individual assessment of influencing factors.

This model is demonstrated under three soil conditions:

1. Dry soil with normal value under fine weather conditions, corresponds to the technogram field T1P2 (Fig. 4): Under these conditions harvesting is very easy; most methods are possible, achievable and acceptable. If it is the most economical method, the fully mechanized method with harvester and forwarder on skid roads with a distance of 20 m is the best choice. If rain should occur during harvest and shifts the matrix field by one field to the right side, (T2P2), then also this method remains acceptable.
2. Fresh soil with high value under dry conditions equals T2P3 (Fig. 5): Here the distance between skid roads is 40 m; therefore fully mechanized methods are no longer possible. The forester examines different alternatives and can decide that a semi- (full) mechanized method fits well. The trees in the crane zone around the skid road are processed by the harvester, that the trees in the zone between these harvested crane zones are felled by chainsaw and processed by the harvester in a second follow-up cycle.
3. Temporarily saturated soil with very high productivity corresponds to T4P2 (Fig. 6): Felling and processing can be done by chainsaw, and the only possible transportation solution being by either cable crane or by heli-logging. Both of these options are dangerous, expensive and in some cases not possible. The Institute for Forest Technology in Tharandt has developed special solutions for those conditions using a bridge-harvester (Fig. 7) and a cable crane which is specialized for flat terrain and small trees.

To summarize, there is a dramatic decay of knowledge surrounding forest mechanization and a foolish acceptance that only fully mechanized methods are “modern”. The combination of the technogram of soil and harvest ecogram of method, allow for easier decision making when finding the best harvesting method, dependent on both the soil conditions and the owner objectives. We hope that a tool like this enables the decision makers to optimize their actions and subsequently to fulfill the demand of sustainable forestry.

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New methods for measuring of dynamic contact pressure under forest tires

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Comparing rut depth, soil compaction and shearing of forwarders with different propulsion systems

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The overall objective was to compare the impact on soil by two forwarders with similar carrying capacity but with different propulsion systems; i.e., an EI-forest F15 (weight 15.7ton, total ground pressure 68kPa) with double frame steering (three axles without bogies), bigger wheels (Ø164 cm), a hybrid engine system that allows individual speed control of each wheel; and a Valmet 860 (weight 17.4 ton, total ground pressure 73kPa) with conventional propulsion (two axles, Ø131 cm wheels, bogie on rear axle) (Table 1).

Parameter	EI-Forest F15	Valmet 860 wheel	Valmet 860 track
Number of wheels	3 pairs	4 pairs	4 pairs
Wheel type	Nokian forest rider	Nokian Forest King F	Nokian Forest King F
Wheel size	710/55 R34	710/45-26.5	710/45-26.5
Bogie tracks	No	No	Yes
Weight (unloaded)	15.7 tonnes	17.4 tonnes	19.3 tonnes
Weight (loaded)	26.2 tonnes	27.9 tonnes	29.8 tonnes
Tyre pressure (front wheels)	2.2 bars	3.5 bars	3.5 bars
Tyre pressure (back wheels)	2.4 bars	5 bars	5 bars
Ground pressure*	68 kPa	118 kPa	73 kPa

Table 1: Properties of vehicles used in the study. The tire pressure corresponds to manufacturer recommendations.

**Ground pressure was calculated dividing weight of the machine by the total contact area from the wheels or tracks on firm ground. Contact area was determined by spraying paint on tracks and measuring the color print on ground.*

Tests were made on soft and flat, homogeneous, arable land and on soil with higher bearing capacity (intermediate forest soil). On soft soil, the rut depth from the un-loaded EI-forest was generally deeper, independent of the number of passages, than from the un-loaded Valmet, both with and without bogie tracks when driving in a straight line, albeit the difference was less than 2 cm after 10 passages (Table 2).

With load, the difference between EI-forest and Valmet with tracks was clearer, reaching about 7 cm after 8 passages. Without tracks, the Valmet forwarder showed almost identical rut depth as EI-forest irrespective of number of passages. When driving in an S-shaped line or in a circular course however, the results become quite different. EI-forest and Valmet with tracks showed same rut depths after the first and after a few passages but with an increasing number of passages the Valmet made deeper ruts and the EI-forest showed clearly less rut depth than the Valmet with tracks at the maximum allowed number of passages (Table 2).

Propulsion system	Number of passages									
	Without load					With load				
	1	3	5	8	10	1	3	5	8	10
<i>Straight</i>										
El-Forest F15	3.4a	5.2a	6.7a	8.3a	9a	5a	7.3a	10a	15a	
Valmet 860	3b	4.3b	5.3b	6.4b	7.3b	4.3b	7a	9.7a	14.8a	
Valmet 860 tracks	2.1c	3.7c	4.7c	6.3c	7.2b	1.7b	4b	5.3b	7.2b	9.3a
<i>Circular</i>										
El-Forest F15	2.4a	3b	4.5b	5.5b	7b	1.9b	5.1c	7.5c	11.8b	13.9a
Valmet 860	1.3b	1.5c	2.1c	5.3b	7.5b	5.2a	8.4a	12.6a		
Valmet 860 tracks	1.3b	4.3a	6.5a	9.7a	10.6a	1.6b	5.7b	9.7b	13.1a	
<i>S-shaped</i>										
El-Forest F15	2.3a	3.1ab	4.2b	5.8c	6.4b	1.5b	4.2b	6.9b	11.1a	
Valmet 860	1.9ab	3.4a	5.7a	7.5a	8.5a	4.2a	8.7a	12.5a		
Valmet 860 tracks	1.4b	2.9b	4.1b	6.8b		1.8b	4b			

Table 2: Rut depth as a function of the number of passages for loaded and unloaded vehicles after driving in a straight or S-shaped line or in a circular course on soft arable land. Means with different letters are different at the 0.05 level of significance according to Tukey's multiple comparison test.*

**Since the landowner did not allow a rut depth above 15 cm full passages were not made if this limit was passed in one of the first measured rut depths or if it was obvious that this limit were to be passed somewhere throughout the passage.*

On soft soil, unloaded forwarders produced significantly lower compaction results for Valmet with bogie tracks than El-Forest after 5 passages and 10 cm depth. After two passages at a depth of 10 cm, Valmet without bogie tracks had about 0.3M Pa higher compaction than El-Forest when comparing vehicles with load. At a depth of 20 cm, for loaded vehicles, the only difference that could be established was between El-forest and Valmet after three passages. In that case, the compaction from Valmet with tracks was 0.3 MPa higher than the compaction from El-Forest (Table 3).

Propulsion system	Number of passages									
	Without load					With load				
	1	3	5	10		1	3	5	10	
<i>10 cm depth</i>										
El-Forest F15	0.7a	0.7a	0.8a	0.8a		0.8a	0.7a	0.6a		
Valmet 860	0.9a	0.7a	0.6ab	0.7a		0.8a	0.7a	0.6a		
Valmet 860 tracks	0.8a	0.6a	0.5b	0.5a		0.9a	0.7a	0.7a	0.8a	
<i>20 cm depth</i>										
El-Forest F15	0.7a	0.6a	0.6a	0.7a		0.9a	0.6b	1.0a		
Valmet 860	0.9a	0.8a	0.7a	0.7a		0.9a	0.8ab	0.8a		
Valmet 860 tracks	1.0a	0.7a	0.9a	0.9a		0.9a	0.9a	0.8a	1.2a	

Table 3: Compaction as a function of the number of passages for loaded and unloaded vehicles for 10 cm and 20 cm depth. Means with different letters are different at the 0.05 level of significance according to Tukey's multiple comparison test.

For all of the vehicles, the soil compaction was highest or almost highest after one passage. When comparing shearing, we found that the tracks after driving in a circle on soft arable land were significantly narrower for EI-forest compared to Valmet without tracks. Without load, the track width was 77 cm for EI-forest and 128 cm for Valmet after five passages. With load, the results were 76 cm and 92 cm respectively (Figure 1)

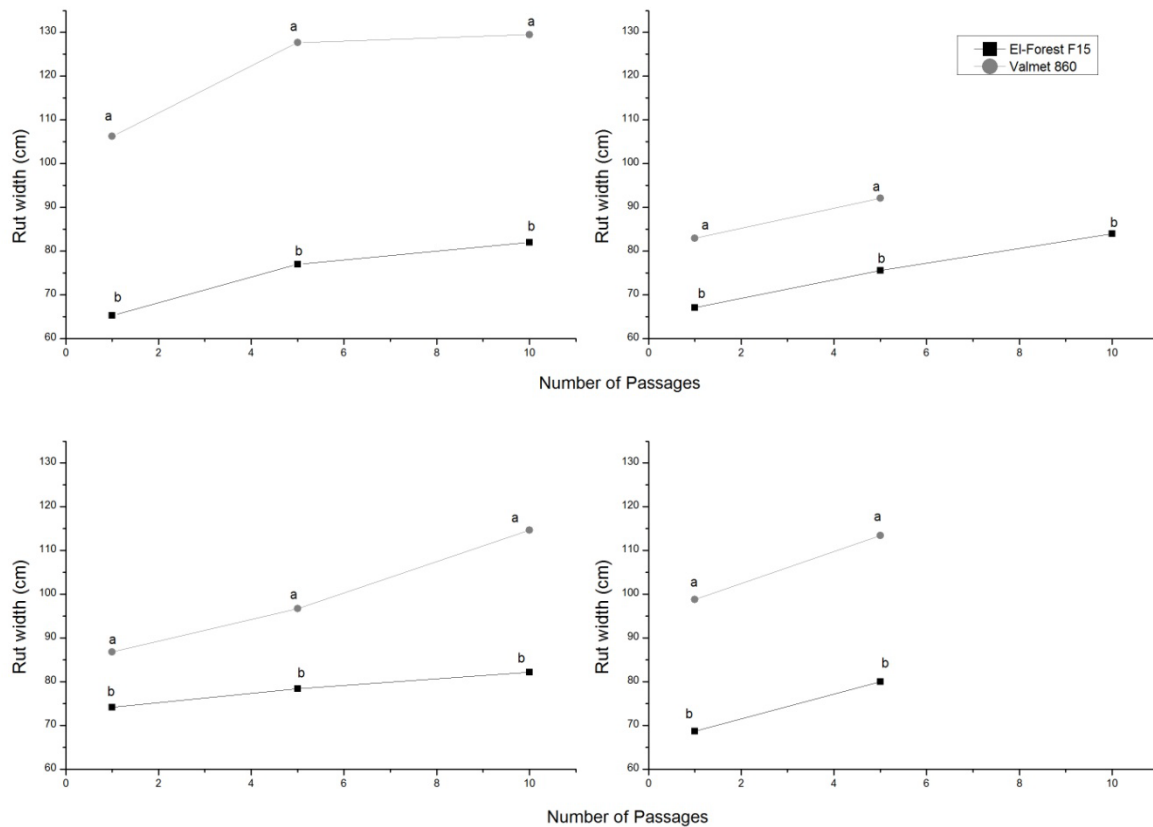


Figure 1: The width of the tracks after driving in a circular course on soft arable land (above) and intermediate forest land and with unloaded (left) and loaded vehicles representing different propulsion systems. Means with different letters are different at the 0.05 level of significance according to Tukey's multiple comparison test. Since the landowner did not allow a rut depth above 15 cm, full passages were not made if this limit was passed in one of the first measured rut depths or if it was obvious that this limit were to be passed somewhere throughout the passage.

When comparing rut depth in intermediate forest land after driving in a straight line, EI-Forest showed smaller values than Valmet (Table 4). After ten passages driving with load, EI-Forest had 3.7 cm shallower ruts than Valmet who had 6.5 cm deep ruts. Almost significant difference ($p = 0.06$) was seen when comparing the rut depth for unloaded vehicles after driving in a circle. When comparing loaded forwarders after driving in a circular course, EI-forest had 5.2 cm lower rut depth than Valmet after five passages (Table 4).

Propulsion system	Number of passages									
	Without load					With load				
	1	3	5	8	10	1	3	5	8	10
<i>Straight</i>										
El-Forest F15	1.4a	1.4a	1.8b	1.5b	2b	4.2b	4.9b	5.7b	6.5b	6.5b
Valmet 860	1.3a	1.8a	2.4a	2.7a	2.4a	6.4a	8.3a	8.7a	9.5a	10.2a
<i>Circular</i>										
El-Forest F15	9.5a	12.8a	14.6b	16.5b	17.7b	6.8b	12.1b	15.2b		
Valmet 860	9b	12.9a	17.3a	16.7a	18.8a	11.6a	14.4a	20.4a		

Table 4: Rut depth as a function of the number of passages after driving in a straight line and circular track on intermediate forest land. Means with different letters are different at the 0.05 level of significance according to Tukey's multiple comparison test.

The width of the tracks from the vehicles was significantly narrower for El-forest, both with and without load. For the unloaded vehicle the mean track width was 82 cm for El-forest and 114 cm for Valmet without tracks after 10 passages while for loaded vehicles the width was 80 cm and 113 cm respectively after five passages.

The overall results indicated that to reduce rut depth on soils with low bearing capacity, a light machine with a bogie system equipped with bogie tracks should be used, at least when driving in a straight line (here Valmet 860 with bogie tracks matches this description). However, the results when driving in an S-form, or in a circular course on soft soil, did not confirm these results. Somewhat surprisingly, El-forest showed clearly less rut depth than Valmet, with tracks at the maximum accepted depth (maximum allowed number of passages).

The deepest ruts were made by Valmet 860 without bogie tracks; the difference was biggest when loaded vehicles were compared. The results should be affected by the bogie tracks used. That El-forest F15 makes narrower tracks, i.e. that the effects from shearing is smaller than from Valmet 860, seems to be an result of that the wheels follow the same track when turning thanks to double frame steering. This explanation might also be one reason to why the ruts from El-forest are deeper on soft soil when driving in straight line than the other vehicles tested in the study.

In conclusion, a vehicle with double frame steering and wheels that can be individually steered seems advantageous especially if the wheels could have reduced ground pressure on soft soils.

Concepts for mechanized tree planting that meet the needs of small forest owners in southern Sweden

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Introduction and Objectives

When compared to the cost of harvesting, the relative cost of forest regeneration in southern Sweden is increasing year after year. Part of this cost increase can be attributed to the lack of mechanization during today's tree planting. In an effort to help promote the development of mechanized tree planting, Sweden's largest forest owner cooperative, Södra Skogsägarna, has contracted two planting machines. These planting machines, which consist of Bracke Planter planting heads mounted on tracked excavators, help rationalize administration, create sought-after continuity during silvicultural work, and increase work quality during tree planting (Ersson and Petersson 2009).

There are, however, some major obstacles hindering the widespread adoption of mechanized tree planting throughout Fennoscandia. First, the planting machines are still up to 25% more expensive than manual planting on average clear-cuts in southern Sweden. This higher cost is mostly because the productivities of today's commercially available planting heads are too low; the maximum reported productivity is 351 seedlings per effective hour with the M-Planter planting head (Rantala et al. 2009). Moreover, seedlings must be manually reloaded onto crane-mounted planting heads. This manual reloading task can occupy from 15% (Rantala et al. 2009) to 35% of the planting machine's effective working time (Halonen 2002) and is one key reason for the low machine productivities.

Second, the Bracke Planter, today's most common planting head, has changed little since it was invented 20 years ago (cf. von Hofsten 1993). This lack of development mirrors the suspicion that foresters and forest owners have towards planting machines; skepticism often rooted in the recent failures of the Silva Nova (cf. von Hofsten 1997) and EcoPlanter planting machines (cf. Saarinen 2006).



Figure 1. The Bracke Planter and M-Planter planting heads (Left photo: Magnus Petersson. Right photo: M-Planter Oy).

Third, because of the short Fennoscandian planting season, planting machines must keep a high machine utilization rate to ensure that the fixed costs are distributed over as many planted

seedlings as possible. This reality places higher demands on the workplace organization of planting machines and requires more efficient seedling distribution, high machine availability and more skilled and motivated personnel when compared to manual planting.

The main objective of this PhD-project is to develop knowledge that can help to increase the productivity and thus decrease the total cost of mechanized planting systems that are relevant for small forest owners in southern Sweden.

Materials and Methods

This PhD-project will focus on making system analyses of existing and proposed technical solutions. These analyses will be made using models, simulations, existing biological results and new technical developments of individual planting machine components (the latter in collaboration with technical universities, Skogforsk and machine manufacturers).

Results

There are many potential improvements to today's mechanized planting systems. So far, this PhD-project has mainly worked with automating the Bracke Planter's seedling feeding and handling system. We commissioned students at the Luleå University of Technology to develop a functioning conceptual prototype for de-plugging seedlings from cultivation trays on the planting head. This conceptual prototype is today being refined into a working prototype by two of these students as part of an MSc thesis. In addition, we have analyzed the total cost of different packaging solutions for transporting seedlings from the nursery to the planting head. This cost analysis compared two conventional packaging solutions with two planting machine-specific solutions developed in the 1990s for the EcoPlanter and Silva Nova planting machines (Ersson et al. 2010).

Presently, we are focusing on simulating the potential improvements of semi-automatic cranes on the productivity of today's crane-mounted planting heads. Some other potential improvements that we expect to explore are modified and lighter planting heads, other types of base machines and enhanced site selection criteria.

Discussion and Conclusions

This PhD-project was commissioned to generate knowledge that will spur the development of planting machines relevant for conditions in southern Sweden. Nevertheless, the knowledge generated will be applicable to other countries so we must source and distribute such knowledge without regard to geographic boundaries. Since planting machine research in Sweden was last carried out about ten years ago, it is important to bridge the gap between historic and contemporary research regardless of the fact that previous research was primarily focused on continuously advancing machine concepts (vs. intermittently advancing machine concepts today).

If we incorporate our results thus far with lessons learned from previous Nordic planting machine endeavors, we are already able to draw two conclusions. First, planting machine concepts must be adaptive to meet the demands of different terrain types, varying site characteristics, and forest owners with diverse goals and silvicultural needs. Second, planting machine development must include a holistic economic analysis encompassing the whole chain from the nursery (cf. Ersson et al. 2010) to the stand regeneration's effects on subsequent silvicultural treatments (cf. Uotila et al. 2010).

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Mechanized harvesting in uneven-aged Norway spruce stands

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Integrating inherent wood properties into the value-chain for best utilization of the forest resource: a case study with tamarack in northwestern Ontario, Canada

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Canada's forestry sector has been on an economic downturn for nearly a decade. Due to the high cost of raw materials, transport and processing the sector has lost much of its global competitiveness. In the last decade in Canada, the forest sector has lost 3% (19 to 16%) of the global market, 90% of this resulting from a decrease in exports to the United States. For Ontario this has meant a decrease in revenues from the exports of pulp and paper and solid wood manufacturing products of 51% and 71% respectively. Over the same period in Northwestern Ontario, 40 wood products manufacturing facilities have closed (4 pulp mills, 26 medium to large sawmills, and 10 value-added mills) representing 82% of the total facilities operating within the region. During this period of downturn for the Canadian forest sector, competition from the forest sector of the Southern Hemisphere has been growing due to the expansion of the fast growing, short rotation Eucalypt and Pine plantations.

Value-chain optimization (VCO) could alleviate some of this loss in competitiveness. However, to realize the benefits of VCO, the raw material resource needs to be fully understood. Currently information does not exist for species relating to their whole stem inherent wood properties. Whole tree mapping of wood properties (mechanical and physical) at the species and site level will lead to a landscape map of the resource allowing maximum utilization and value realization.

Tamarack (*Larix laricina* (Du Rio, K.Koch)), also referred to as Larch, was used as a case study species in Northwestern Ontario to compare two systems relating to the processing and realization of inherent value based on wood properties. The product mix optimization model "BUCK-2" developed by the Ontario Forest Research Institute (OFRI) was used to quantify the product mix from logs based on inherent wood properties. Valuation was conducted on the basis of 750 trees per hectare. Current lumber prices from the Random Lengths (2009) statistics for Eastern Canada were used for valuations in the model. Projected values based on these lumber prices were calculated for harvesting and processing System 1 compared to harvesting and processing System 2.

In System 1, traditional harvesting and processing of the tree was used where the entire tree length was processed as one unit. In System 2, value-chain optimization was utilized where inherent wood properties were included in the decision making process for end processing and utilization. In System 2, the entire tree length was segregated into three zones of statistically similar wood properties within each zone but dissimilar between each zone. The segregation was based on a study by Miller et al (2010) who identified three broad zones of axial similarity, and three zones of radial similarity in Tamarack grown in Northwestern Ontario. Each of these zones of similarity display properties, which will affect end use product potential. "BUCK-2" was used to quantify the optimal product mix from logs based on inherent wood properties and harvesting and processing techniques. Based on current lumber prices, projected values were calculated for System 1 compared to System 2. Using inherent wood properties in the decision making process where trees, or portions of trees are processed, increased the trees value by 25.33% from \$30,363.70/ha for System 1 to \$38,056.22/ha for System 2.

Using inherent wood properties in landscape mapping of tree species and properties should allow the forestry sector to become more competitive by utilizing all parts of the tree in the most efficient manner while attaining the highest value for the resource based on inherent wood properties. For example, axial variability in the sapwood of Tamarack indicates that products such as lumber, pulpwood and bio-products can be produced from all three axial positions; however, products such as timbers, veneer, moldings and structural lumber can only be produced from logs in the bottom zones of the tree. Radial variability produced similar results with regards to end use suitability and the heartwood of Tamarack was found to be best suited for outdoor applications such as post and poles, fencing and bio-products. The heartwood was not predicted to be suitable for glue-laminated products due to the high extractive content. The properties of Tamarack are suitable for many end use products, realizing and mapping the inherent wood properties as they vary throughout the tree will allow existing harvesting systems, such as cut-to-length, to be utilized to implement segregation of the main stem of a tree in the bush, therefore working with current forest operations. This will increase the value for many species and promote value-adding industries in the forest sector where more potential products based on the inherent properties of this species could be manufactured.

Larger loads and decreased damage – the potential of a new forwarding concept

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Investigating a new wood biomass based bioenergy system: A case of Atikokan Power Generating Station in Ontario, Canada

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As part of Canada's strategy to reduce greenhouse gas emissions, the Ontario provincial government adopted a regulation in 2007 that will phase out the generation of electricity from coal at Ontario Power Generation's (OPG) coal-fired generating stations by December 31, 2014. In February 2009, the Ontario government also announced its Green Energy Act (Bill 150) which is aimed at expanding renewable energy generation and strengthening the province's commitment to energy conservation [1]. Since 2005, OPG has been investigating the use of biomass as a coal offset option. In order to contribute knowledge on how to expand bioenergy, this paper examines a case of success from Ontario, Canada. Compared to other renewable energies such as wind and solar, biomass has the added benefit of responding to the changing load demand when needed. Other benefits related to a large-scale biomass energy industry in Ontario are the synergies with agriculture and forestry sectors and the favorable economics of using existing provincial assets (the coal plants). The principles for OPG's biomass testing program are as follows: OPG does not use food products fit for human consumption; it only uses biomass extracted using sustainable practices; and OPG intends to maximize the use of existing assets [1].

Biomass is becoming a major component of the renewable energy and fuels picture for Canada. At present, Canada produces 6% of its total energy consumption from biomass [2]. Bioenergy is a complex topic and many aspects are associated with it such as socio-economic impact, greenhouse gas mitigation potential and environmental impact [3][4][5]. Currently, forest contractors and other stakeholders in the Atikokan region are facing economic hardships, as much of the local forest industry has closed or has reduced their production. Consequently, the majority of forest industries are not undertaking all of the prescribed harvesting operations on their allotted crown forest land. As a result of mill closures and production reductions, there is an abundance of unutilized forest resources in northwestern Ontario. This unutilized biomass is vulnerable to pest attack and the wildfire [3]. The Ontario government also loses stumpage revenues. At the same time, energy consumption of northwestern Ontario's First Nation communities is increasing [2]. These First Nation communities consume large amounts of fossil fuels for heating their homes and other community institutions, as well as in the generation of electricity with diesel generators. Continued reliance on fossil fuels for meeting growing energy needs will increase the energy security concerns of these First Nations communities. By building synergies between the existing forest industries and the emerging bioenergy industry, a win-win situation will develop that will ensure the health of the entire sector, as well the region and communities involved.

The Ontario Government has investigated the possibility of replacing lignite coal with renewable forest biomass as feedstock at the Atikokan Power Generating Station (APGS). The APGS is a 227 MW capacity plant and is equipped with a single Babcock & Wilcox natural circulation boiler of opposed-fired design [1]. The APGS currently fires lignite coal delivered by rail from Saskatchewan and has a baseline coal consumption capacity of 40.8 t/h. In a series of tests during January to July 2008, a total of 1,622 t of commercial grade pellets were used at various levels of co-firing and 100% pellet-based feed stock [1]. The first pellet-based test at the APGS was during January 2008. This test consisted of 26 t of wood pellets that were co-fired with coal

at a wood pellet flow of 5 kg/s and a cold primary airflow of 20 kg/s. With this test a significant reduction in SO₂ emissions was observed. In March 2008 a second co-firing test was conducted with the complete displacement of coal on a single burner row. In this test, 181 t of pellets were used and they accounted for 20% of the furnace energy input level. The cold primary airflow was at a base value of 20 kg/s and the wood pellet flow was 6.8 kg/s (24.5 t/h). In May 2008 a third co-firing test with 177 t of pellets was run. During July 2008, a series of tests over the month were conducted to assess the plant's potential to operate on 100% wood pellet fuel. During early to mid-July, 796 t of pellets were used in various tests with one of the tests in mid-July using 100% pellets. On July 31 a 100% run of pellets was made and 442 t were used [1]. Some of the important results [1][6] from these tests were as follows:

- *Startup with Wood.* The test was started with initial firing on natural gas followed by 100% wood pellets.
- *Energy Balance.* During the test the primary air heater (PAH) gas outlet temperature was seen to increase by >40°C to approximately 200°C and then stabilize following adjustment of the gas-balancing damper.
- *Steam Temperatures.* At wood energy input of 67% and 100%, both the main steam and hot reheat steam temperatures were observed to be well below their design values on coal.
- *Primary Air System Limitations.* The capacity of the existing PAH system was found to be marginal at full unit load on 100% wood pellet firing. The cold primary airflow available was approximately 18 kg/s; 10% below the target value.
- *NOx Emissions.* By 100% wood firing NOx emissions was changed from 1.50 kg/MWh (for coal) to 0.53 kg/MWh (with pellet).

The economy of Atikokan is based on forestry, the power generating station, government services, retail services, tourism, mining and a mixture of light manufacturing businesses [7]. At present, the leading employer for residents of Atikokan is APGS. It is responsible for providing 90 well-paid jobs and a significant amount of tax revenue for the Township of Atikokan. Without its revenue and jobs, the Township of Atikokan will face a huge financial problem [8]. A company named Atikokan Renewable Fuels is now in full control of the former Fibratech Mill, which went into receivership in November of 2007. Atikokan Renewable Fuels is investing an initial \$15 million to renovate the plant to produce 140,000 t/year of industrial wood pellets that could potentially be used in the APGS. When the wood pellet operation is up and running in Atikokan, the company anticipates 40 jobs will be created. The company is also planning to build 60,000 t/a wood pellet plants at White Sand and Sand Point First Nations. In August 2010, the Ontario Government gave the go-ahead for the conversion of APGS from coal to biomass. Atikokan Power Generating Station is now planned to generate 21 MW electricity using 100,000 t/year of pellets [3][8].

As shown above, the conversion of the APGS to fire 100% wood pellets as feedstock is technically feasible. But in addition to technical feasibility, a suitable policy environment is essential for promoting and sustaining the growth of any sector in the economy. For this a SWOT (strengths, weakness, opportunities and threats) analysis was conducted in 2009 at Atikokan and seven surrounding First Nation communities among the general public, contractors, women, students, seniors, First Nation Chiefs, and other professionals (non-governmental organizations, government, industry, academia, etc.) to recognize their perceptions regarding forest biomass-based bioenergy development at the APGS. From the SWOT analysis at Atikokan, 'Create Employment' was mentioned as the most important function of bioenergy development. As Atikokan is suffering from the closing of its main forest industries, this might be a cause for this perception. Normally, the quantity and quality of employment in the

bioenergy sector depends mainly on the overall bioenergy system cycle: i.e., production, conversion and end use [9]. It is a labor-intensive process. At the APGS, pellet-based bioenergy is being promoted due to its potential contribution to energy security, environmental appropriateness and ease of plant conversion. It is hoped that deployment of bioenergy has the potential for job creation in the community, improved industrial competitiveness, regional development and the development of a strong export industry.

Keywords: Technology adaptation, Bioenergy, Wood biomass, Sustainable development.

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Energy consumption and emissions in selected biomass supply chains

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Energy from renewable resources, including biofuels, has received considerable attention in recent years. In order to assess the energy gain represented by biofuels, the amount of energy required for harvest and transport the biomass must be weighed against the final energy produced.

The aim of this study was to determine the energy consumption of different forest fuel supply chains. Three different chains were analyzed as follows: stemwood, small diameter trees and logging slash. The entire chain from harvesting to final delivery to energy plant was included in the analysis. By-products from the forest industry, stumps and indirect energy use, such as construction of machines, roads etc., were not taken into account.

Through comparing different logistic chains and systems, it was possible to determine which operations were more energy effective than others. The analysis was based on previous productivity and fuel consumption of harvesting, chipping and transportation of industrial wood and forest fuel research. Out of that data, the total energy consumption for the complete chains was calculated.

The results demonstrated that the direct energy consumption by harvesting and transportation of forest fuel is very little when compared to the energy output of the fuel. For a typical supply chain from forest to energy plant, the input versus output of energy was approximately 3.2% for stemwood, 2.8% for small diameter trees and 2.5% for logging slash.

It is important to note that there are a number of uncertainties when calculating the fuel consumption for the various supply chains. For instance, variable transport lengths significantly affect consumption. In addition, it is important to consider the energy content represented by the specific product harvested and transported. There is a large difference between harvesting oak stemwood, which has high energy content, compared to harvesting small diameter spruce with low middle dimensions. Finally, there are variations between harvest seasons such as in winter when deep snow levels result in increased forestry machine fuel consumption.

Table 1. Consumption of diesel oil divided on different assortments. Litres of diesel / m3 solid of wood supplied.



Keywords: Energy consumption, forest machines, energy wood supply.

The impact of road characteristics on fuel consumption for timber trucks

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In Sweden, transport accounts for more than 25% of the supply cost of timber from stump to the industry. Of the transport cost, one third consists of the cost of diesel fuel. It is important, both from an environmental and transport cost perspective, to find ways to lower fuel consumption.

Many factors affect the fuel consumption in wood secondary haulage; weight, velocity, road surface, driver, truck configuration, curvature and more. Many of these factors are poorly investigated in Swedish forestry. Knowing the influence t characteristics of different roads is essential when choosing between alternative driving directions, planning investments in road improvement or setting up cost models for truck transportation.

A study is being set up with the objective of measuring the impact of road characteristics on fuel consumption for truck transport during transport on different ground conditions. The measurements refer to a conventional, self-loading, timber truck with gross vehicle weight (GVW) of 60 tons. The study will include the impact of GVW, horizontal and vertical curvature, road bearing and road surface. The study will, through regression analysis, produce a mathematical function that describes the impact on fuel consumption of the factors mentioned above.

This is study one in a PhD project that is part of FIRST (Forest Industry Research School on Technology), - a joint Swedish – Finnish initiative to strengthen competitiveness in forestry.

GIS for operative support

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Abstract

Geographic Information Systems (GIS) is often used for planning purposes in forestry. The primary uses are to give direction to operators as to where to cut the trees and to mark areas with high environmental values and special considerations. A less commonly used technique is to incorporate soil information maps as an overlay which gives routing information to operators as to where difficulties can be expected, particularly after heavy rain. By marking areas with poor bearing capacity, the operators may save both time and money by avoiding bogging down the machine.

When the soils bearing capacity is less than 0.7 MPa and the ground pressure of the machine is more than 80 kPa, either smaller machines must be used or bogey tracks should be used to decrease the risk of severe rutting or the machine getting stuck. Through choosing good types of bogey tracks both rutting and fuel consumption will be decreased, a benefit to the contractor and to the forest health.

Full paper available on request of author.

Fuel consumption driving with a forwarder on soft ground

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Abstract

One of the major focuses of Swedish forestry is to decrease the fuel consumption of forestry work. At the moment, it is estimated that the average fuel consumption is 1.7 l/m³ harvested wood from stump to landing and half of it emanates from the off-road transport of timber. The forwarder, the machine that carries the timber from the stand to the landing, is the machine that causes the most damage to the ground and where improved transmission can make the most benefit. We have studied rut formation after machines and fuel consumption with only wheels and with different types of bogie tracks on 8 wheeled loaded forwarders. On soft ground, the good types of bogie tracks reduced fuel consumption considerably due to better floatation on the ground and thus making less ruts.

A model was made with the soil bearing capacity measured as cone resistance and calculated ground pressure of forestry machines versus the rut depths in the soil collected from number of studies, including our own. It is clear that at soils with a soil strength below 0.7 MPa actions should be taken to keep the ground pressure of the machine below 75 kPa. That would also reduce the fuel consumption and be environmentally friendly by both reducing soil damage and emissions from the engine.

Keywords: Forestry machines, soil damage, specific fuel consumption

Full paper available on request of author.

Poster Session

Session Chair: Mark Brown

Using GIS and AHP tools to define maintenance priorities of primary forest road networks – an Alpine case study

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Extended abstract

Routine road maintenance is a vital activity to keep a road system serviceable and to maintain proper working of its drainage system. A well-maintained road can be protected from rapid deterioration and sediment production (Dubè et al. 2004). Another benefit is reduced trucking costs (Brown, 2000).

Each year, a consistent amount of money is spent to upgrade and maintain forest road networks. In order to optimize the use of a limited economic budget, it is essential to set investment priorities that meet the management and environmental goals. The resulting task is complex because many of the aspects involved in forest road management are related to the natural environment and the socio-economic context in which the forest road network is located. Because of this, the management of forest road networks needs methods to integrate multiple objectives and set priorities across these different areas. In addition, the management of forest roads involves a mixture of both environmental data and models with social factors and expert judgments.

Managers generally focus on specific problems to better understand the condition of the road network and to set maintenance and upgrade priorities. The Washington Department of Natural Resources and Boise Corporation, for example, have created an empirically based model (SEDMODL), used to estimate road-related sediment production and transport to streams (Dubè et al. 2004).

The Analytic Hierarchy Process (AHP) appears to have the potential for managing existing road systems where research has not yet uncovered quantifiable relationships between cause and effect. As a result, the synthesis of road inventory data in order to set investment priorities should depend, in part, on professional judgment. According to this idea, Coulter et al. (2006) developed maintenance priority definition methodologies that use AHP analysis in order to minimize the environmental impact to soil and water resources from forest roads.

AHP analysis and GIS tools have also been used to evaluate both the needs of forest roads in a mountainous area (Cavalli et al. 2010) and the road location alternatives (Abdi et al. 2010).

The present work uses the combination of GIS tools and AHP technique to define the maintenance priorities in an Alpine area in Italy (Figure 1).

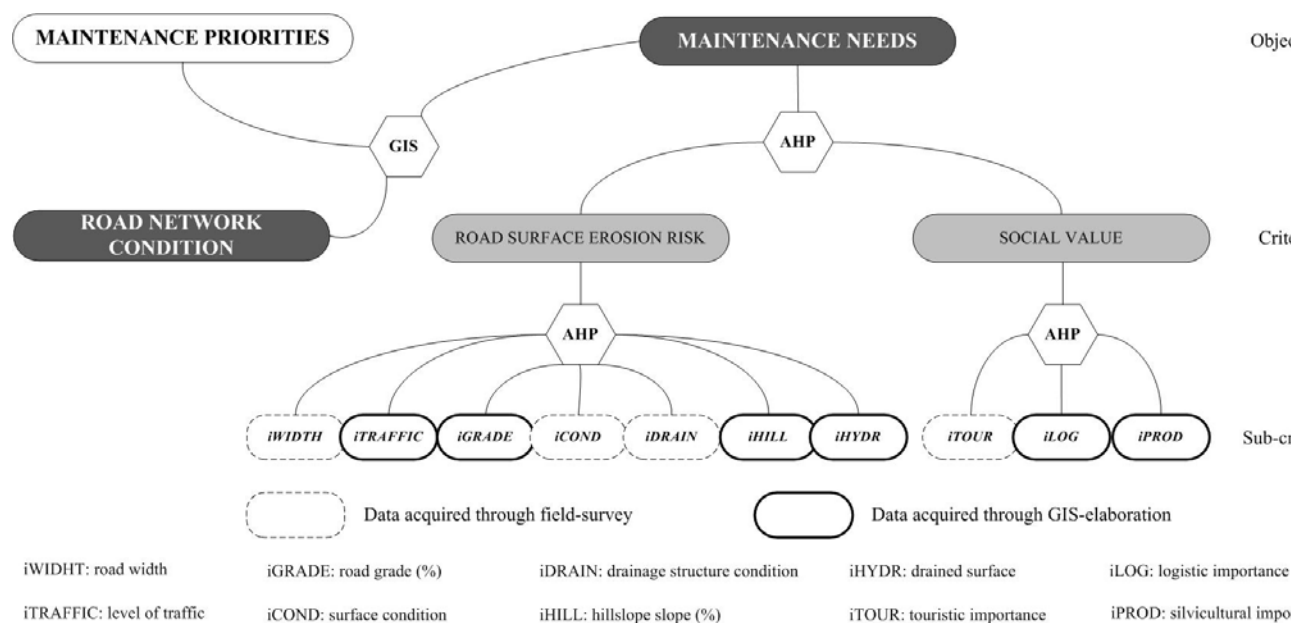


Figure 1. Layout of the study

The study area is within “Altopiano dei Sette Comuni” in the northeastern part of Italy (latitude (N) of 45.56 – 45.52 longitude (E) of 11.23 – 11.28). This region is mainly occupied by Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) forests.

The most problematic issues in forest road network management were found by examining both the stakeholders’ interviews for the studied area as well as field inspections of the same area. These issues were found to be the forest road surface erosion, with subsequent sediment production, and the socio-economic importance of the road for the community.

Sediment can be eroded from all road components but road surface erosion is generally the dominant source of sediment (Ramos-Scharron and MacDonald, 2005). A recent review paper on the surface erosion and sediment delivery model for unsealed roads (Fu et al, 2010) effectively describes the main factors highlighted in literature.

The basis for the development of a road maintenance plan is a thorough understanding of the road system characteristics and needs. The most important characteristics of each forest road have been collected and organized in a *geo-database* structure. The surveyed information was as follows: road width, surface type, surface condition, traffic limitation, the presence and efficiency of drainage structures, and the functional and operative classification.

Road maintenance activities normally performed in the studied area have also been analyzed. The maintenance operations have been divided into the following 4 basic types: drainage structure cleaning, ordinary surface maintenance, non-ordinary surface maintenance and drainage structure installation. All of the maintenance interventions that occurred in the last 3 years have been monitored and mapped in order to determine the mean annual budget. In total, 208 maintenance interventions have been analyzed. The mean cost of each type of operation has then been determined through project analysis and the total cost of upgrading the forest road network has been calculated.

The GIS elaboration was finalized to have all the needed data about the forest road network in raster integer format. Through field survey, all the necessary information on forest road design and condition has been acquired. Data about width, condition, and the presence/absence of drainage structures extracted from the forest road inventory have also been converted into raster format. To calculate the socio-economic value, each road has been rated according to its importance for accessing different sites (touristic site, high productive area, farming structure). The relative importance of each factor has been determined through interviews with the stakeholders of the area.

To determine the productive importance the data from the management plan of the area, concerning the type, the growing stock and the increment rate of the different forest area have been analyzed.

The analyses have been supported by the software ArcGIS 9.3 and by the tools AHP 1.1 (Decision support tool for ArcGIS) (Marinoni, 2004).

The use of integrated GIS tools and AHP analysis shows that different aspects can be effectively integrated so the approach could be used to improve the administration and management of effective maintenance planning.

AHP gives the opportunity to the stakeholders to analyze different scenarios, defining the importance of the relative function of each road. The results shows different ranking in the management priorities according with different objective and given economical budget.

The comparison between the optimal and the actual maintenance intervention and resource allocation can be used as a basis for the future planning strategies.

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